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ABSTRACT

The five papers presented in this volume discuss the relationship between the psychomotor domain and instructional technology and are intended to serve as resource materials for instructional technologists. The first chapter focuses upon a consideration of the senses of reality and the second upon some general considerations of the psychomotor domain. The third paper offers a classification of educational objectives in this area, and the fourth considers some educational implications of the structure and measurement of psychomotor abilities. The concluding chapter, a joint effort of four authors, examines the impact of four major factors upon psychomotor performance effectiveness. These factors are environmental stressors, time/work fatigue, toxic and drug effects, and task loading. (LB)

The Psychomotor Domain

THE PSYCHOMOTOR DOMAIN

A CSC Mediabook

The National Special Media Institutes is a consortium of Michigan State University, University of Southern California, United States International University and Syracuse University.

Contributions of Behavioral Science to Instructional Technology

As a consortium of higher education institutions the National Special Media Institutes (NSMI) represents a joint effort to work on projects of national interest which are significant to the development of the field of instructional technology. A series of seminars sponsored by the U.S. Office of Education and coordinated by the Teaching Research Division of the Oregon State System of Higher Education probed the relationship between the behavioral sciences and the field of instructional technology.

The first seminar was devoted to the cognitive area, the second to the affective area and the third to the psychomotor area. Because of keen interest in the affective area the results of that seminar were published first. These three volumes represent new substantive inputs to the field of instructional technology. As the field grew out of its traditional audiovisual product orientation, new insights were required to emphasize the process approach. The behavioral sciences seemed to have more to contribute in this vein than any other substantive field.

The credit for these volumes and the work of the National Special Media Institutes should be given to the late Dr. James D. Finn of the University of Southern California who originally conceived the consortium and stressed the need for new inputs to the growing field of instructional technology.

The papers included in this publication were written pursuant to a grant from the Bureau of Educational Personnel Development, Office of Education, U.S. Department of Health, Education and Welfare.

CONTRIBUTIONS OF BEHAVIORAL SCIENCE TO INSTRUCTIONAL TECHNOLOGY 3

The Psychomotor Domain

—A Resource Book for Media Specialists

Published for the National Special Media Institutes

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Contents

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Floyd Urbach was Director of Individualized Instruction and Instructional Development Program, Teaching Research, Monmouth, Oregon. He was Director of the Psychomotor Domain Conference and Institute at which these materials were presented to the directors of Media Specialist training programs

Robert N. Singer is the Director, Motor Learning Research Laboratory, Department of Physical Education, Michigan State University. His introductory paper is designed to establish some general parameters of the psychomotor domain and to raise issues related to the definition of terms in the psychomotor domain.

Elizabeth Simpson is a Research Associate, Instructional Materials and Practises Branch, Division of Comprehensive and Vocational Research, National Center for Educational Research and Development. A number of taxonomies exist for guiding the instructional developer in writing or classifying psychomotor learning activities. This classification system has been used extensively as an initial conceptualization for students new to the psychomotor area.

George Greer is the Manager, Biotechnology Department, Aerospace Systems Division, Boeing Company, Seattle Washington. His chapter is a collection of papers prepared by George Greer, James D. Hitt, Thomas Sitterly and Edward B. Slebodnick. This unique effort was one of the highlights of the psychomotor conference and draws together significant data related to the psychomotor performance.

Edwin A. Fleishman, Senior Vice President of the American Institutes for Research is Director of the Washington Office of A.I.R. in Silver Springs, Maryland. In this chapter an established author in the psychomotor field presents summaries of an exhaustive series of research studies related to laboratory studies and field surveys conducted on a complex array of psychomotor skills and abilities.

Preface

There has been a considerable emphasis on the cognitive and affective areas of education, but relatively little attention has been given to the psychomotor area. The publication of the *Taxonomy of Educational Objectives: the Cognitive Domain* by Bloom, *et. al.* and the *Affective Domain* by Krathwohl, *et. al.* helped to focus attention on two major aspects of the total educational scene but a taxonomy of the psychomotor domain prepared by the same group has never appeared.

As instructional technologists have been attempting to provide new substantive dimensions to the field by soliciting contributions of the behavioral sciences, both the cognitive and affective domains have been studied. The psychomotor void was recognized by the Directorate of the National Special Media Institutes and the third in a series of conferences regarding behavioral sciences and instructional technology sponsored by the United States Office of Education was held in Oregon early in 1970.

In a pattern similar to the previous conferences, distinguished psychomotor psychologists were invited to prepare definitive and interpretive papers regarding the relationships of their special field to instructional technology. These papers were discussed by the psychologists and a team of instructional technologists in an attempt to elicit areas of application. The papers were then revised by the original authors in light of the comments made during the conference. The basic chapters, however, do not attempt to highlight applications but, rather, serve as resource documents for instructional technologists.

Some translation of the conference papers was made for a four day institute designed for instructional technologists and held at Detroit in April, 1970. The products used at that session, and other related materials, are listed in the Appendix. This publication was field-tested at the institute which was primarily intended for directors of programs sponsored by the Media Specialist Program of USOE.

With the publication of this volume, the series concerning the relationship of the behavioral sciences to instructional technology is complete. These efforts are an attempt to bring new dimensions to the field. The *resources* are provided in these publications, the applications must necessarily rest with the practitioners.

The vision and strong support of L. Clinton West of the Bureau of Libraries and Educational Technology of the United States Office of Education helped to make the conferences and publications a significant contribution to the field and to the larger Educational community.

Donald P. Ely May 1970

The Senses of Reality: The Psychomotor Domain

Floyd Urbach
Teaching-Research—Monmouth, Oregon

Life is commonly characterized by movement. A mother detects the first early movements of the fetus; the newborn child's most obvious changes are in perception and muscular coordination; the developing child is known to be normal largely by muscular coordination; the young adult, although generally unaware of his physical well being, displays great physical energy and stamina; the middle aged adult begins the slow atrophy of motor abilities, compensating by experience and habit; failing coordination, reduced flexibility and loss of speed become the symptoms of old age; the total loss of reflex activity and muscular responsiveness results in disability or death.

In education there is a tendency to forget that man is an animal and to deal with man only as an intellectual being. Generally little attention has been paid to the psychomotor domain by most educators. Few curriculum areas devote more than a passing mention to this domain in spite of the generally recognized importance of motor skill coordination and of many specialized programs which are concerned with psychomotor skills.

A folk song being sung today asks, "If there is to be a tomorrow what must be today." The song could be paraphrased to reflect a critical concern of education: "If there is to be a day after tomorrow, what must education be like tomorrow?" One part of the answer may lie in the psychomotor domain. In an era of increasingly complex technology the importance of the physical well being of man is becoming increasingly critical. If adults are to have the physical proficiencies and abilities which successfully complement the "after school" components of our culture then education must be concerned that children do not lack the prerequisite psychomotor abilities simply because they were permitted to atrophy through neglect in the educational system.

The psychomotor domain is concerned with more than human development. It is more than children playing with blocks, or learning to play the piano. It is more than physical fitness exercises or training to work on an assembly line. A simple theoretical definition of the psychomotor domain remains elusive. A confounding factor is that the psychomotor domain cannot be neatly separated from the cognitive or affective components of man. Psychomotor abilities are meshed with perception of stimuli as well as the control of movement resulting from those stimuli. Each of the authors in this publication will address himself to defining either parameters of the domain or to establishing ways of working with variables in the domain. The net result of this Behavioral Science Conference is not a neat conceptual package but rather a vortex of ideas which reflects the present status of thought, research, and experience in the psychomotor domain.

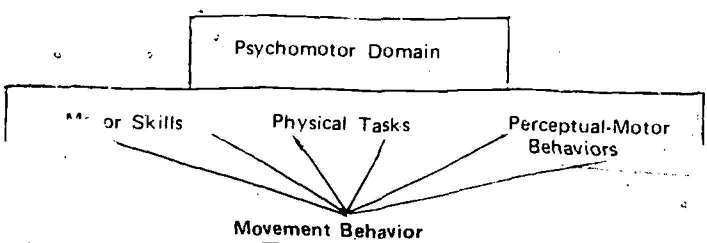
Psychomotor Conference and Institute

The psychomotor domain is concerned with the physical activities of the body such as coordination, reaction time and muscular control. Despite a long history of attention in the elementary schools, physical education areas and in some vocational areas, many educators and researchers have ignored this area of knowledge. The philosophy of the psychomotor conference and institute was to probe this area of human behavior and to look for possible applications to learning and to teaching.

A writers conference was held early in February 1970 (Appendix I). During the three and a half day conference a panel of five scholars, seven media specialists, and eight observers explored the content, research, and findings in the psychomotor domain. The first problem was simply to establish a common vocabulary so that discussion could take place.

The first vocabulary "handle" was provided by Robert Singer who was at that time from the department of Health, Physical Education and Recreation of Michigan State University (currently at Florida State University). The psychomotor domain was represented as illustrated below.

This simplified model, when enlarged to include skill factors, task factors, and behavior factors plus a consideration of how movement behavior



is related to how we think, how we perceive and how we feel, provided a point of entry into the psychomotor domain.

Edwin Fleishman, Senior Vice-President and Director of the American Institutes for Research, provided an in-depth look at the domain presenting the results of 18 years of intensive, sustained research in the area of psychomotor abilities and physical proficiency tasks. In a series of interlocking and carefully controlled studies 12 "basic abilities" have been identified by correlational and factor analytic studies. They have such names as tracking, control precision, response orientation, rate control, arm-hand steadiness and multi-limb coordination. The precise definition of each of these abilities and the accompanying research evidence indicates that there is no such thing as generalized motor skill capability. The measurement of an individual's psychomotor ability requires a comprehensive battery of tests and measures in each of the twelve areas.

Two terms, ability and skill, require specific definition. An ability, in Fleishman's terms, is a general trait inferred from response consistencies: A skill is a level of proficiency on any given task or limited group of tasks. A skill, then, may require several psychomotor abilities to complete the sequence of responses required by the task.

Elizabeth Simpson, Research Associate, Instructional Materials and Practices Branch, of the National Center for Educational Research and Development of the United States Office of Education, presented a taxonomy developed to assist educators in developing and analyzing educational objectives in terms of the psychomotor domain. This landmark work which provides a six level taxonomy does *not* attempt to classify psychomotor abilities or skills but seeks to provide a base for *stating and analyzing educational objectives* in the psychomotor domain which are at present, implicitly or explicitly, in educational programs.

The basic dimensions of this system are *perception, set, guided response, mechanism, complex response and creation.* At this point in the conference it became very clear that educational objectives in the psychomotor domain overlap the cognitive and affective domains. The taxonomy of psychomotor objectives, while admittedly subject to much modification, was undertaken when it became apparent that educators investigating the other domains had no intention of pursuing a similar kind of effort in the psychomotor domain.

The fourth paper was presented by a quartet of writers from the Biotechnology Division of Boeing Aerospace. George Greer, Jr., Daniel Hitt, Thomas Sitterly and Edward B. Slebodnick compiled a unique paper, several hundred pages in length, which includes an enormous amount of research data resulting from the aerospace program, human factors research and industrial applications. The principle sections of the paper deal with time-work effects on learning and performance, toxic and drug effects on psychomotor performance, task loading and operator performance.

The scope of implications regarding performance and learning to perform include: 1) the value of overlearning; 2) the effect of environmental variables on performance requiring a large cognitive learning component; 3) the value of physical conditioning; 4) deterioration of secondary tasks under stress; 5) adaptation to stressors; 6) the value of motivation and the need for motivation management; 7) the problems of learning which arise from the instructor-student interaction in the learning situation; 8) the effect of deficiencies in man-machine interfaces which degrade performance; 9) the techniques of establishing performance standards; 10) learning how to better use visual capability; and. 11) the effects of common drugs and toxic agents on performance (which appears to be far more critical than present legal requirements indicate).

This outstanding effort contains a data base capable of not only modifying the design of the learning of psychomotor skills but also modifying the way in which learning is designed and the conditions under which we require pupils to learn.

What is the role of the psychomotor domain in educating children of today and of tomorrow? This is, of course, the ultimate question. Some of the answers may lie in the papers and deliberations of this conference.

The Institute. From the conference papers and deliberations came the ideas to be presented in the psychomotor institute. The institute was a three and a half day learning experience for the directors of 1970-71 Bureau of Educational Personnel Development funded media institutes. The institute included representatives from 16 states and represented a major dissemination effort of this behavioral sciences project. The second dissemination effort was to publish the papers resulting from the conference in order to make them available to the total academic community. The Final report of the project contains a complete summary of all experiences and materials used in the Psychomotor Institute. Appendix II presents the Institute outline Appendix III presents a list of mediated packages and materials used at the institute.

Summary

The relationship of psychomotor proficiency to intelligence and emotions is a matter of some speculation. Research evidence is contradictory and research designs generally discourage generalizations. However, the involvement of psychomotor abilities in cognitive acts and affective reactions seems fairly obvious after even minimal study of the psychomotor domain. The implications for instructional technologists, curriculum designers and instructional systems developers are less obvious. Only by conscious effort will the appropriate use of our knowledge about the psychomotor domain be made. The instructional technologist has a responsibility similar to that of the aerospace technologist to make practical uses of psychomotor knowledge by applying that knowledge to the design of environments which use available information about the psychomotor capabilities of man.

The psychomotor domain holds catalytic keys to individual learning styles and also to the design of more effective instructional methodologies. Each instructional technologist is challenged to attempt his own synthesis through integration of psychomotor elements with those in the cognitive and affective domains.

The Psychomotor Domain: General Considerations

Robert N. Singer
Florida State University

The psychomotor domain encompasses a broad spectrum of movement behaviors. It is no different from the affective and cognitive domains with regard to acknowledged difficulties in the interpretation and agreement in the usage of relevant terminology. In the psychomotor area, the problem is magnified further by the fact that different disciplines have interests in, and produce research related to, man's motor activity. Because each has developed its own body of knowledge, the consolidation of research findings applicable to all forms of human activity has been difficult. Psychomotor activity is associated with military tasks, agricultural duties, industrial, professional, technical, and vocational skills, secretarial functions, business operations, home economics responsibilities, driving demands, music, art, and dance works, as well as physical education, sport, and recreation endeavors. It underlies other forms of behavior as well. Although the skills of each field are unique, common bonds tie these areas of interest together. Great reservation and caution must be observed, however, when applying nomenclature and research in the psychomotor area.

Perhaps a clarification of terminologies would be a first logical step in an attempt to order and classify research findings in the psychomotor domain. Following this will be discussions on (a) psychomotor behavior, (b) the objective: proficiency, (c) the learner, and (d) instructional settings.

Definitions and Interpretations

The development of various terms within and among different disciplines, vocations, and professions to explain movement behaviors has caused a fair amount of confusion among researchers, teachers, and laymen alike. The same terms have been used in different contexts. Dissimilar terms are utilized to convey the same meanings.

Thus, the physical educator develops his own "jargon," as does the psychologist, the technologist, the vocational specialist, the special educator, and the like. It becomes evident that the psychomotor domain encompasses many if not all of man's overtly expressed movement behaviors. Cognition and affect are entwined in all volitional motor activity. Therefore, the distinction among domains becomes one of convenience rather than one of natural boundaries. Assuming the association of overt activity with the psychomotor domain, the task is then to classify or categorize behaviors in a meaningful way. Only then can research on behavioral expectancies be meaningful.

Various reports have been published, attempting to make sense out of the psychomotor domain. In response to the taxonomies developed within the cognitive and affective domains, Dr. Elizabeth Simpson has formulated a taxonomy of the psychomotor domain which is discussed in Chapter 3 of this volume.

Other researchers have been concerned with providing order to certain aspects of the domain. Hence, Guilford (1958) has surveyed psychomotor abilities through the administration of physical fitness tests, apparatus tests, and printed tests. He concludes that there are six primary psychomotor abilities: strength, impulsion, speed, precision, coordination, and flexibility. Guilford's means for collecting data may be criticized and his conclusions questioned. His designated psychomotor abilities appear to have limited real applications to the wide variety of activities that may theoretically be placed in the psychomotor domain.

Fleishman has gone a step further in identifying dimensions underlying human performance. He classifies factors in two categories: the physical proficiency (fitness) area (Fleishman, 1964) and the psychomotor area (Fleishman, 1967).

Physical Proficiency	*Psychomotor Factors*
Extent Flexibility	Control Precision
Dynamic Flexibility	Multi-limb Coordination
Static Strength	Response Orientation
Dynamic Strength	Reaction Time
Trunk Strength	Speed of Arm Movement
Gross Body Coordination	Rate Control
Gross Body Equilibrium	Manual Dexterity
Stamina	Arm-Hand Steadiness
	Wrist-Finger Speed
	Aiming

It should be pointed out here that the psychomotor factors established by Fleishman are the result of performances on various laboratory tasks.

The extent to which these factors underlie athletic performance, success in music, art, and dance, worker output, and military achievement has yet to be ascertained. Nevertheless, we may conjecture that the physical proficiency items are most associated with athletic, military, and industrial tasks requiring strength and endurance primarily and minimal intricate coordinated movement patterns. Psychomotor factors would be more related to those skills represented by fairly refined activity.

Cratty (1966) has attempted to construct a theory of what he calls "perceptual-motor behavior." This three-factor theory is illustrated in Figure 1. Although there is consideration for environmental conditions and the status of the organism, there is serious doubt as to whether his "General Supports of Behavior" are indeed general but rather specific to each given situation. Furthermore, the indentification of ability traits seems to suffer from a lack of those psychomotor factors, e.g., coordination, isolated by Fleishman as well as others.

From another frame of reference, the schema depicting the parameters of movement is presented in Figure 2. A more philosophical approach is represented here. Nevertheless, Abernathy and Waltz (1964) touch upon a number of the considerations for effective movement. Although primarily applied to expressive movements rather than vocational and occupational skills, this approach reflects thinking in the psychomotor domain.

The semantics involved in the psychomotor domain have been exposed in a few instances. For example, Lockhart (1964, p. 9) writes that:

> . . . investigators naturally communicate in language familiar to them. The behavioristic psychologist concerned with motor learning might be expected to use the term psychomotor. The experimenter interested primarily in the functioning of the sense organs performs sensory-motor investigations. Those concerned with perceptually guided, non-verbal behavior often refer to perceptual motor-learnings.

And finally, I (Singer, 1968) have found fault with the misuse and abuse of certain terms in the physical education literature; namely, physical fitness, motor fitness, motor educability, motor capacity, and motor ability. Used interchangeably on many occasions, these terms were conceived to describe different conditions of the organism that might, ironically enough, not even exist. What is physical fitness? Motor ability? How are they to be measured? Agreement is lacking in definitions as well as the nature of the tests to measure such human dimensions. Without an adequate validity criterion, the very nature of the value of these tests is questioned. The typical loose usage of the terms results in added confusion for all concerned.

Is there any hope of establishing the boundaries of the psychomotor domain? Of identifying and distinguishing tasks that constitute this domain?

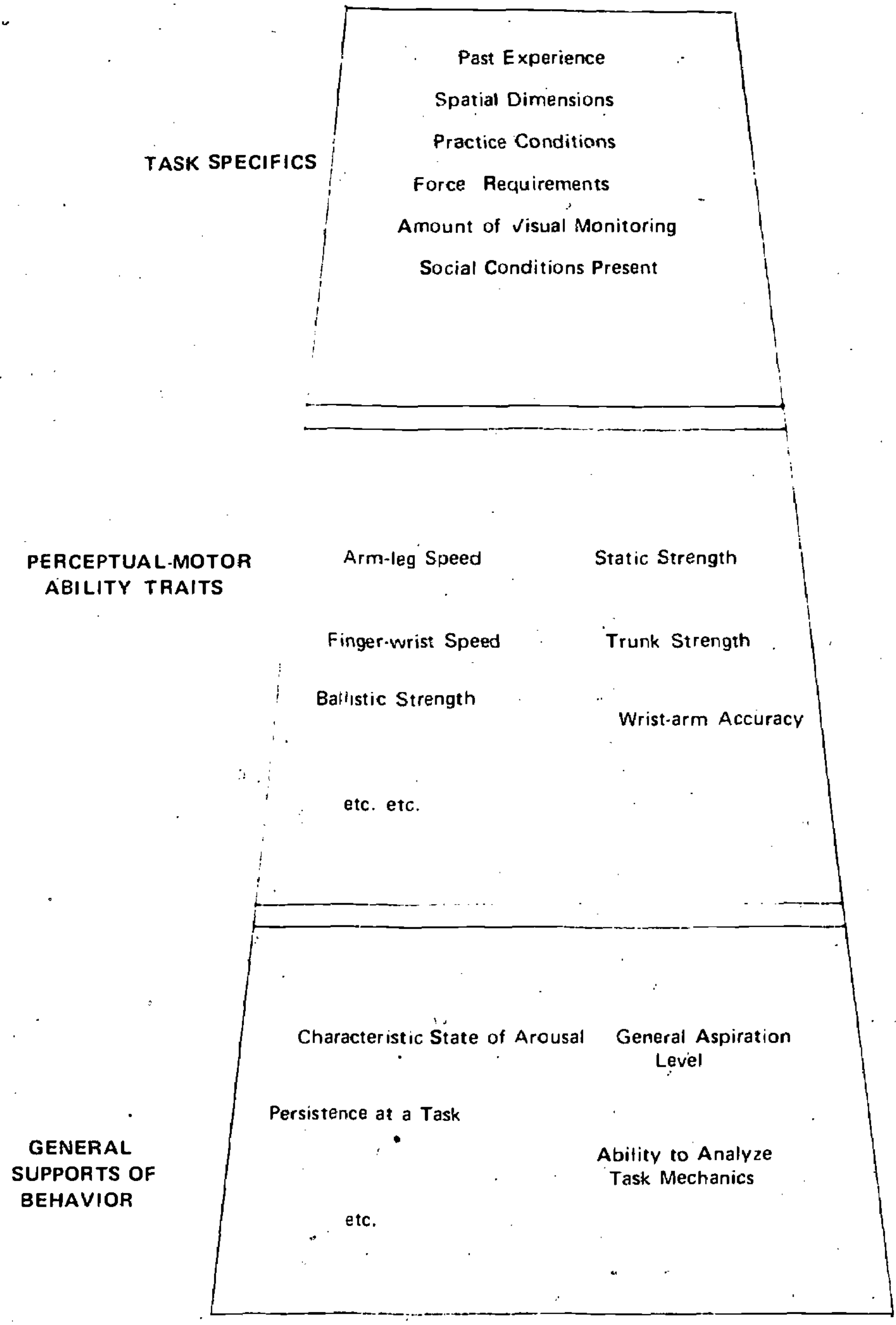


Figure 1. A theory of motor behavior. (From Cratty, 1966)

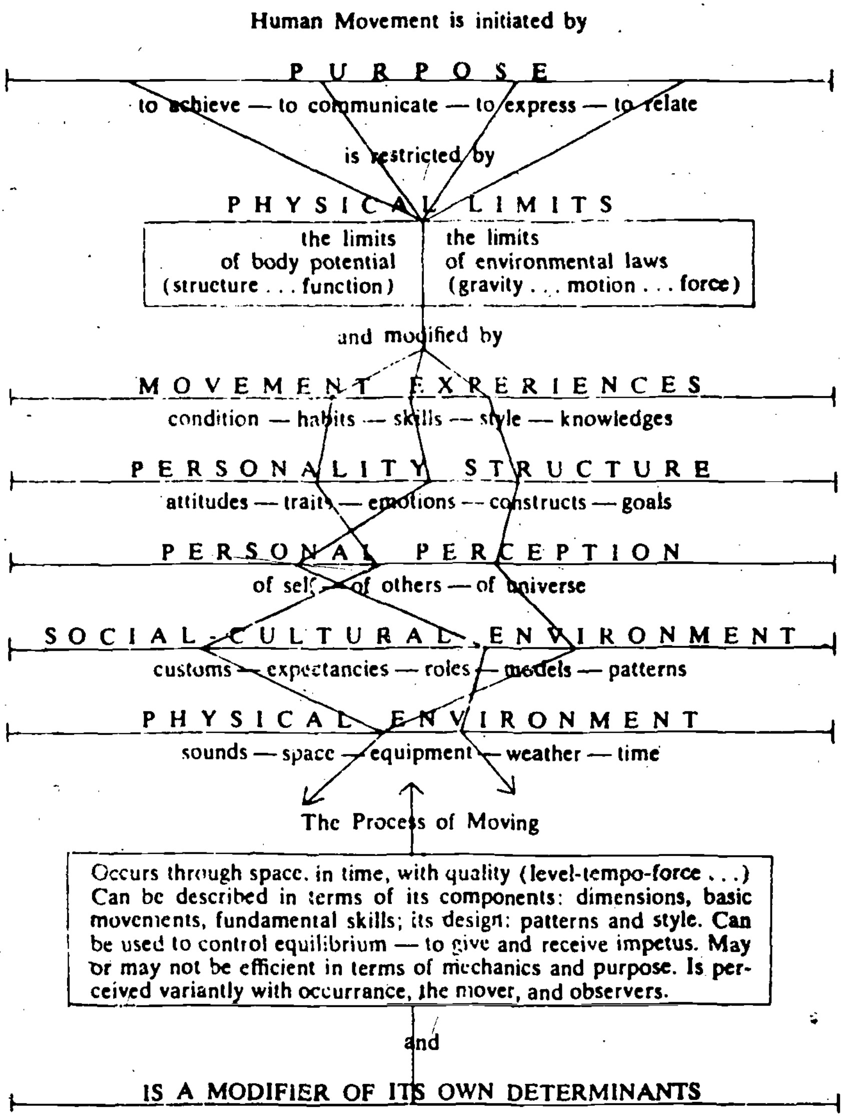


Figure 2. A Framework and Structure of Human Movement. (From Abernathy and Waltz, 1964)

The charge is obviously not an easy one. Nevertheless, Figure 3 depicts the possible scope of the psychomotor domain and the kinds of abilities leading to various acts which constitute movement behavior (no continuum of activities is intended):

I. A motor skill refers to muscular movement or motion of the body required for the successful execution of a desired act. (Same as perceptual-motor skill.) Specific criteria are set for the acceptability of performance.

   A. *Fine motor skills* encompass the neuromuscular coordinations involved in precision-oriented tasks, such as typing, piano playing, watch-making, needle-threading, and tracking with pursuit rotors. They are highly refined and distinguished from other tasks because of the high degree of eye-hand precision required in their execution. Furthermore, they are usually sitting-down tasks.
   B. *Manual skills* are typically mid-way between fine and gross skills. They are usually eye-arm-hand manipulative tasks that are fairly repetitive. Examples are found in factory work and industrial technology areas. Equipment, apparatus, or objects are usually the source of manipulation.
   C. *Gross motor skills* involve the large muscles and the movement of the majority of the body. Sports skills of all kinds may be considered as gross motor skills, although there is no clear-cut distinction between fine, manual, and gross motor skills.

Further distinctions might be made according to the nature of the task. Fitts and Posner (1967, pp. 83-84) describe discrete, serial, and continuous skills in the following way. A *discrete* task has a clearly defined beginning and end, as is found in the typical reaction time experiment. A *serial* task contains a number of successive events that are also encompassed by well-understood beginning and ending parameters. A musical selection or reading exemplifies serial tasks. A *continuous* task involves adjusting sequential responses to unpredictable stimuli, as is incorporated in the act of driving a car.

II. Physical tasks are characterized by a minimal, if any, involvement of the higher cortical centers of the nervous system.

   A. *Physical fitness tests* require minimal coordination of body parts and cognitive activity. Strength, endurance, speed, and flexibility describe factors in this category. Following an understanding of the act, the execution of it becomes quite repetitive, with stimulus discrimination of minor importance. Gross motor skills, as alluded to before, include activities demanding cue discrimination of changing and unpredictable stimuli and the temporal patterning of adaptive responses, e.g., sports skills. Physical fitness tests accent the "physical," that is, a push-up test demands gross, continuous, predescribed movements of the body until the onset of fatigue. Motor skills are more complex and involve more motor coordination of

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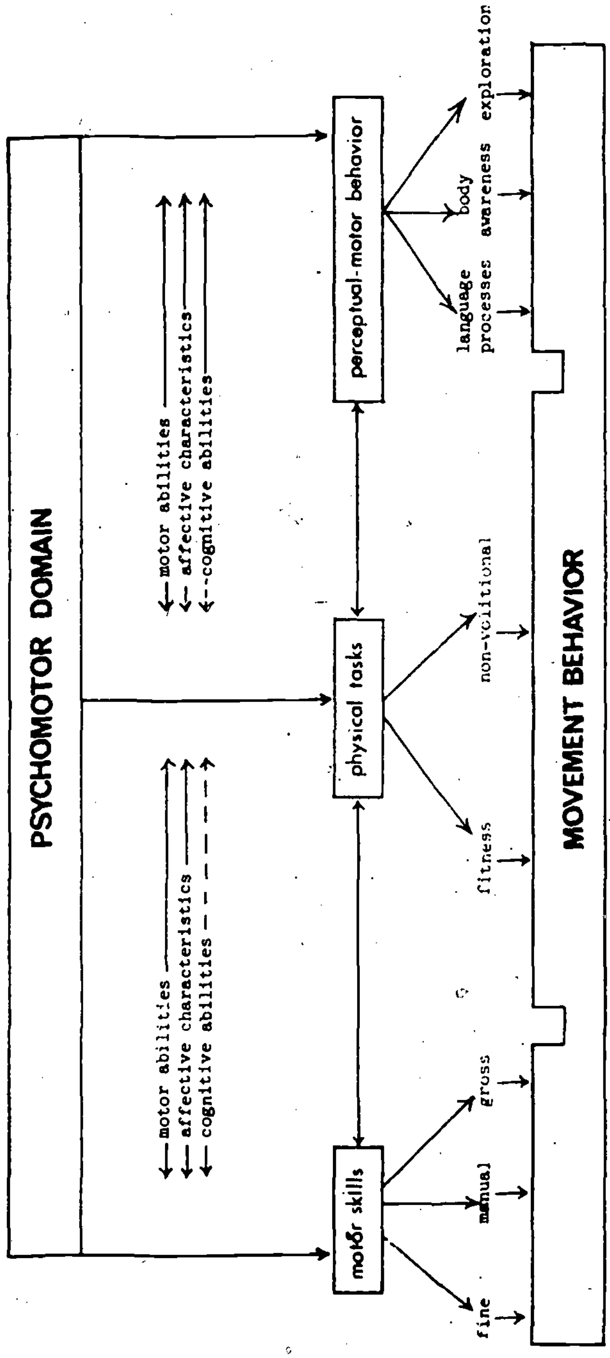


Figure 3. A schematic plan of the factors included in the psychomotor domain.

the body itself, as well as more coordination of cognitive and motor abilities.

B. *Non-volitional* behavior is primarily reflexive. The knee jerk, autonomic processes, and extremely well-learned acts are probably performed at a sub-cortical level.

III. Perceptual-motor behavior includes those tasks that have a high degree of the perceptual component present. It is popularly used to connote the special training programs for youngsters classified as mentally retarded, emotionally disturbed, or slow learners, in the hope of improving their learning capacity. The perception and recognition of spatial relationships and patterns, the estimation of distance, speed, and accuracy, and the ability to temporally pattern responses could easily describe motor skill as well as perceptual-motor behaviors. But for distinction between these terms, motor skills refer to *specific* acts and sequences of responses while perceptual-motor behaviors are more *general* movements. In comparing motor skills with perceptual-motor behaviors, relatively speaking, there is a greater emphasis on response development in the former case. A greater degree of the perceptual component is present in the latter case, as is allowance for varied behavioral expression.

A. *Exploration* of space and body awareness activities represent perceptual-motor movement patterns. Moving and controlling appropriate parts of the body in space to reach objectives demonstrate body awareness and space exploration activities. In perceptual-motor training programs, these are general, appropriate, relatively non-difficult movement responses to specific directions, involving the interpretation of directions and the activation of acceptable responses.

B. *Language skills* are heavily perceptually-oriented and reflect perceptual-motor behavior. The conception of words, the formation of mouth movements and facial expressions, and the production of words describe activity in this area.

No reference is made to psychomotor tasks *per se*, for almost any kind of movement-oriented task could probably be considered a psychomotor task. For the most part in the literature, psychomotor tasks are indicated by laboratory-created situations. Reaction time, coordination-apparatus tests, positioning tests, speed tests, and the like have often been referred to as psychomotor tests. The term is so vague as to have little real practical meaning.

Contrarily, Noble (1968) argues that "the label 'motor' skills is less satisfactory than 'perceptual-motor' or 'psychomotor' skills . . ." He feels that the two latter terms are interchangeable in meaning. Motor skills are defined as "merely . . . any cued striate-muscular action that is modified by learning variables." Psychomotor tasks (or perceptual-motor) are elaborately interpreted to be "those situations that require the identification and combination of stimulus-organism-response elements into coordinated spatio-temporal patterns of receptor-effector activity as a joint function of practice repetitions and reinforcing feedback so as to optimize probability, amplitude, and time scores (or their derivatives) in acquisition, retention, and transfer." It is my opinion that to get bogged down in semantics, terminology and verbosity, will do us no good at this symposium. We need simple explanations to understand the scope of the psychomotor domain.

A general framework has been suggested as to the types of tasks representing the psychomotor domain. Research on motor skills will now be primarily considered with regard to learner and environmental variables. Proficiency in skills is dependent on so many factors that it will be impossible to mention them all in this paper. No depth-treatments of these considerations can be made. Research will be examined from the motor skills area in order that applications can be made without the usual fear of the possible lack of relationship between the learning of nonsense syllables, prose, and other verbal material with the learning of motor tasks. Although research findings are argued to be task and situation specific, hopefully evidence on the learning of certain types of tasks in the psychomotor domain may legitimately be applicable to other tasks in this domain.

The Objective: Proficiency

Although there may exist a number of objectives in the learning situation, one of the immediate or ultimate goals is the mastery of the task and the attainment of skill. Different standards of achievement are established, but essentially the most efficient and effective ways of reaching goals are those that are sought. This implies a need to understand the nature of the task, the learner, the learning process, and learning conditions.

In the area of athletic proficiency, a number of factors contribute. They may generally be described as found in Figure 4. Genetics, childhood experiences, personal goals, environmental influences, and other interactions lead to the state of "excellence." Ideally, in order to determine potentials for developing proficiency in any task, genetic factors, familiar tendencies, past experiences, and the individual's personality would be reasonably understood prior to training on a given task in a particular situation. General learning principles and specific considerations, with appropriate environmental modifications and instructional techniques, would then be utilized. The coach is thus the ultimate determiner of the athlete's productivity. Limiting and determining personal factors on the part of the athletes are incorporated in the coach's plan in directing practice sessions. Figure 5 has been drawn to show parallelisms between the characteristics considered in Figure 4 for athletic proficiency with those underlying achievement in any vocational task. In this case, it is the teacher, leader, or supervisor who has the final responsibility in shaping the environment for best productivity.

In most learning situations in any domain, it is virtually impossible to

Athletic Proficiency

Coach's guidance:
coach-team-athlete compatibility
Environmental conditions-
Behavioral Modification

Influence of culture,
family, peer group

Interest, motivation

State of training,
physical attributes

Prior athletic experiences,
learned skills

Childhood experiences

Hereditary factors, e.g.,
physical characteristics, abilities

Figure 4. Foundational blocks toward achieving excellence in athletics. (From Singer, in press)

Task Proficiency

Teacher, leader, or supervisor guidance:
leader-group-individual compatibility
Environment of conditions
Behavioral Modification

Influence of culture,
family, peer group

Interest, motivation

State of training,
physical attributes

Prior learned specific,
related skills

Childhood experiences, general

Hereditary factors, e.g.,
physical characteristics, abilities, intelligence

Figure 5. Foundational blocks toward achievement in vocational skills.

make all these individual considerations. Yet, one of the fallacies in any group-learning effort is to treat all individuals as if they possess the same characteristics, abilities, experiences, and motivation to achieve. For instance, it is suggested that approximately 80 percent of the variance in intelligence may be attributed to hereditary factors; 20 percent to environmental experiences. When all sorts of familial characteristics are considered, e.g., intelligence, height, weight, and body build, an average correlation of .50 is obtained between parents and children. To the extent that such personal qualities may be related to the probability of success in a given endeavor in the psychomotor domain, they must be acknowledged.

1. In athletics, a given *body build* has been found to be related to excellence in particular athletic endeavors. The average athlete representing one sport has been somatotyped (a method of determining body build) and is usually distinguished in this dimension from athletes representing other sports (Carter, 1968, 1969). Or, for that matter, from so-called non-athletes. Although a given body type is not a necessity for excellence in athletic endeavors, its presence may increase the probability of success. The relationship may hold true for all types of motor skills. Inherited and developed personal qualities may increase the likelihood of one accomplishing certain activities associated with industry, business, the military, and the arts. Physical characteristics, of little concern in the cognitive domain, are very much associated with the mastery of varied motor skills.

2. Enriched and varied *early childhood experiences* is a second factor leading to the probability of success in a wide range of undertakings. Work with lower forms of young organisms chimpanzees, chickens, dogs, and rats introducing an experience, depriving or restricting a sense or enriching the environment has been shown to affect adult behavior. (For example, see Beach and Jaynes, 1954.) Freud's work and the efforts of subsequent psychoanalysts indicate the effect of early experiences on adult personalities.

Situations for figuring-out and executing appropriate movement responses begin at a very early age. These foundational blocks serve the learning of later-in-life complex activities. The extent to which a child successfully experiences perceptual-motor behaviors and develops motorically will probably influence his rate of achievement when confronted with so-called "new" tasks. However, it might be theoretically argued, and it has been, that very few activities are really new to the learner following the childhood years. Most skills require that already-learned movements be put together in a different fashion. Temporal and sequential patterns of responses are altered from situation to situation. But essential and general movement patterns, learned well in childhood, influence the degree to which complex skills will be attained in later years.

3. *Specific skills*, once learned, will naturally favorably transfer over to situations in which these skills are used. Specialized training in childhood

leads to desirable outcomes in specific circumstances. These exists much evidence on the specificity nature of motor skills; that in order for one to reach a high degree of proficiency in any skill, practice must be specific to that skill.

4. Aspects of *personality* relate to task achievement in some ways, although clear-cut patterns are often difficult to establish. On more complex tasks, studies generally show highly anxious individuals do more poorly than those low in anxiety. Also, those who score low on anxiety tests perform more effectively under stress than under normal conditions. This is not the case with high-anxiety people, who are less effective performers under stress (Wiener, 1959).

Insight and sensitivity on the part of the teacher, supervisor, or other forms of leadership to the personality characteristics of the learner-performer may help to detect possible behavioral choices, patterns, and achievement. In the area of choices, vocational researchers and theoreticians point to level and direction of vocational aspiration, self-esteem, need to achieve, and other personality characteristics. Self-esteem is a strong moderator variable in one's vocational decisions (Korman, 1966). Individuals are more apt to favor social roles, positions, and occupations that are consistent with their image of personal abilities and talents.

Athletes representing different sport groups have been shown on occasion to possess unique personality profiles. Superior athletes, average athletes, and non-athletes are also uniquely characterized. (A brief summary of the research is reported by Cooper, 1969.) A few psychologists, notably Oglivie (1968), are quite enthusiastic about the identification of unique personality dimensions of champion athletes. However, agreement on these matters is still lacking. When traits can be ascribed with a reasonable degree of confidence to athletes representing a sport, or workers involved in certain occupations, statistical analysis will help to predict the probability of an individual's achievement on a team, in an event, or at a position.

5. The *general motor abilities*, influenced by hereditary and environmental variables, and possessed by the learner will certainly have a bearing on his potential for successful achievement in any endeavor. In predicting proficiency, a young child is more apt to have more "generalizable" abilities than high school or older-aged individuals. With age comes a maturation and differentiation process. Complex and specialized tasks must be continuously and conscientiously practiced for one to attain relatively high degrees of skill as he develops to maturity. Less time can be devoted to other pursuits. The endeavors of youngsters demand more gross movements and they are fairly similar from activity to activity. This is not the case as the individual begins the adolescent years. The maturing organism is capable of undertaking and completing more highly refined tasks. Interests, too, change, and become more specialized.

Obviously, then, *a test that presumably measures general motor ability is* *almost meaningless* in differentiating among the reasonably or highly skilled. Since none have been developed that are truly general, each is almost meaningless for instructional design. In the case of sport, gross bodily activity along with intricate and refined movements are involved. One test, or even a battery of tests, can not conceivably produce discriminating judgments among athletic individuals and between specific sports participants. Specialized skills tests, related to the sport at hand, will do a more acceptable job. The same is true in the vocational area. Instead of speaking about one manual ability, recognition should be given to the probability that there exists a number of manual abilities. And specific manual tests, related to the task at hand, will yield better distinctions among individuals than will a test of general manual ability.

Even so, successful job completion or athletic participation are related to so many variables that the practice of isolating particular skills to test for classfication and prediction purposes is of questionable value. More simple motor skills can be handled more easily with tests when such is the intent. But complex tasks, involving not only a number of human abilities, but specified skills, personality variables, and physical and physiological characteristics as well, defy the implication that an ability test or abilities test alone can satisfactorily account for enough of the achievement variance to be of practical value.

6. Another point to keep in mind is that *initial levels of profiency* are not necessarily valid as the basis for predicting future achievement levels in a given endeavor. Although there are fast learners and slow learners, a person is not typically an overall fast learner (within the "normal" population). Rather, achievement in each task is obtained in varying speeds and at different levels for each individual. For example, there is no confirmation of any general learning ability improvement factor.

When motor tasks are simple and isolated, different trends appear. As in the case of Adam's (1957) data, later proficiency was very much related to early status. The task was very simple, measuring discrimination reaction time. There is good reason to believe, though, (and research support as well) that the relationship between initial and final status is quite low on more complex motor tasks. This is especially true when enough practice and time are alloted for learning to occur.

When individuals have practiced a skill for a while, prediction of relative achievement within a group becomes easier and more accurate. Performance becomes more stable. But as Fleishman has pointed out in a number of articles (e.g., Fleishman and Hempel, 1954), the number and nature of abilities related to task achievement apparently change in relative importance during practice and improvement in complex motor skills. Different abilities are more important in different phases of skill acquisition.

The preceding material constitutes some of the general individual learner considerations in reaching high degrees of skill. The learning situation is dynamic and complex. All learners do not come to the same situation with the same potentiality for proficiency. They cannot be programmed in similar fashion, regardless of the rationale presented by behaviorists. It is true, however, that certain instructional modifications will generally affect the majority of learners in like nature, or with a reasonable degree of predictability in a certain direction. Where applicable and possible to implement, instructional techniques and learning strategies should reflect the learning process in general as well as individual differences.

Let us take a further look at learner dimensions (personal factors that distinguish among members of a group) and behavior modification in general through environmental manipulations (instructional settings).

The Learner

Some of the ways in which learners differ from each other in characteristics as they confront a learning situation striving for proficiency have been summarized. The list needs to be extended. I am continually amazed at the apparent neglect of these variables by psychologists in the experimental and military areas. For instance, Gagné (1962), in an excellent article (to be referred to again in this paper) entitled "Military Training and Principles of Learning" provides much insight into training techniques and behavioral modification. He never once mentions anything about the nature of the learner. He does not address the problem of individual differences.

Learner variables are incorporated in Figure 6, which serves as a summary for the material to follow in this section. Individual differences such as these need to be recognized as important contributors to achievement in many of the tasks found in the psychomotor domain. The nature of the tasks will greatly determine the relative importance and influence of each factor on learning and performance.

In gross motor tasks, often executed in the military, industry, and sport, differences in body build constitute a factor in potential achievement. This point has been alluded to previously. Other factors, besides the ones described in the preceding section, must be examined. Therefore the section excludes material already considered above, (1) body build, (2) childhood experiences, (3) prior specific skills, (4) certain aspects of personality, (5) some general motor abilities, and (6) initial levels of task proficiency, although all are learner considerations. There are other learner variables to consider.

(7) *Physical measures.* If the task requires gross movements of the body (a large-muscle task), adequate strength, flexibility, and endurance must be present. Practice can then be sustained which will in turn result in performance improvement. The condition of the body with respect to those and other underlying personal attributes relevant to the skill(s) at hand will greatly determine the effectiveness of the practice conditions arranged for

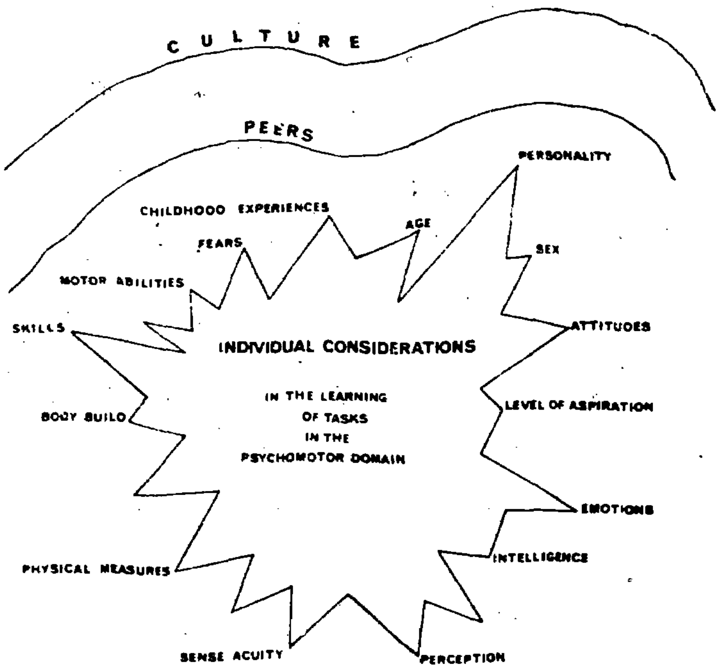


Figure 6. The Learner

learning to occur. Even in such acts as typing, piano playing, and card sorting, finger, wrist, and arm endurance is a prerequisite to skill acquisition.

(8) *Motor measures.* More complex tasks require the presence of a high development of those motor abilities that will interact and underlie achievement. Unfortunately, abilities are usually defined within the framework of the tests designed to measure them. Beyond empirical observations and scanty research evidence, it becomes difficult to specify those abilities associated with task proficiency. Thus, we talk in terms of a coordination ability, an ability to balance, and a speed ability, and yet research has been fairly consistent in demonstrating low positive intercorrelations among tests purported to measure each one of these, as well as other abilities.

Evidently, at the present level of knowledge, we can only talk in terms of an ability as measured by whatever means we measure it. Theoretically, though, an ability contributes to proficiency in a number of skills. A number of abilities are important to complex skill learning. The goal is to be able to specify those abilities related to the learning of each motor task, the stages of learning where each contributes the most to achievement (as attempted by Fleishman and Hempel, 1954; Fleishman, 1957; and Fleishman and Rich, 1963), and the means to emphasize and develop those abilities of interest.

(9) *Sense acuity.* Prior to, during, and following an act information is transmitted through the senses. Kinesthetic, visual, and verbal cues provide important knowledge to the learner about his performance. Various kinds of sensory receptors, each specific to one stimulus form only, convert the input into electrical energy capable of going to various parts of the nervous system. Some impulses activate the perceptual mechanism, so that meaning can be made of that which was sensed. Others activate sub-cortical centers.

In order for information to be accurately processed, as a first step the input devices (sense organs and receptors) must be in good functioning order. Poor depth perception or peripheral vision, inferior audition, or ineffective proprioceptive activity will provide error-filled information.

(10) *Perception.* Following the reception of information through the senses, perceptual operations typically precede motor activity. Interpretation of the situation must be made before correct responses can transpire. Selective attention to cues and disregard for irrelevant ones constitutes the preliminary portion of effective movement behavior. How and what one perceives in a given situation depends on many factors. In turn, one's behavior reflects perception and the means to appropriately spatially and temporally execute movements.

(11) *Intelligence.* Intelligence, which is usually measured by academic achievement or IQ in the research, is positively but lowly related to physical characteristics and motor skills in the normal population of students. Within the normal intelligence range, we would generally not expect those

who are more outstanding in motor skill accomplishments to be meaningfully more or less intelligent than others. Mental retardates, however, usually demonstrate poorer motor development and skills than similarly aged "normals."

With regard to training techniques, there is a possibility that brighter students may learn motor skills more effectively than less intelligent ones (a) under whole rather than part learning methods, and (b) with problem solving methods rather than traditional methods. Low academic achievers (slow learners, mental retardates) require simple explanations and step-by-step progressions in motor tasks.

(12) *Emotions.* Emotions are a part of most motor activity. Researchers have considered the effect of anxiety, stress, tension, and various motivational procedures on the learning and performance of motor skills. Anxiety level and its interaction with task complexity has been discussed earlier in this paper. With regard to emotions in general, an optimal level exists for the learning of any task. Stress, in the form of social presence, high incentives, and the like, is usually a hindrance to the learning of new complex skills. At later stages, it is of no bother or may even facilitate performance.

(13) *Level of aspiration.* The goals established by an individual when he undertakes a motor task will greatly determine his achievement. Previous failures and successes determine the level one sets for himself. It is usually found that high, realistically attainable goals produce the most favorable results for the learner. The implication here is that general group standard performance expectancies, as set by the teacher, for example, are not conducive to a favorable learning climate. Individual status and individually-set goals should be considered.

Early successes are important to motivation, in turn for continuing performance, and ultimately in learning. Performance expectancies should be contingent on prior personal accomplishments and potential achievement. Satisfaction achieved elevates the level of aspiration which in turn increases the probability of better performance output.

(14) *Attitudes.* A person's expectancy attitudes are related to task performance. When an individual has high expectancies, his performance is positively affected. Various investigators concerned with job analysis, e.g., Lawler (1968), have demonstrated that expectancy attitudes are indications of motivation to perform.

Attitudes may also be viewed in another way. Interest in the task, a desire to achieve well, effort, and motivation lead to more meaningful practice sessions. The learner must have intentions of improving his performance. Merely going through routines in a haphazard and mechanical manner, disregarding important cues, and demonstrating purposeless activity is a good example of how not to master a task. One's attitude toward the task at hand is reflected in his attempt to improve himself and the ultimate consequences.

(15) *Fears.* Although not considered in other areas, the psychological fear of success has been of great concern to psychiatrists, psychologists, and coaches dealing with athletes. Some athletes have been diagnosed as being afraid to stand success, or at least failing to whole-heartedly attempt to achieve. They deliberately injure themselves to gain sympathy or even a hero's recognition. They complain of pains that do not really exist. It is interesting to speculate on how many, confronted with any kind of task, fear success. The added responsibility associated with achievement may be looked upon as a cause of increased anxiety by the person.

It should be added, of course, that the task itself may be fear-inducing because of its very nature. Gymnastic, trampolining, diving, swimming, and other athletic skills contain fear situations and require safety precautions. Military, vocational, and driving skills have similar elements. Fear, causing anxiety, is a deterrent to the learning process in such activities.

(16) *Sex differences.* With regard to occupational choices, athletic endeavors, and task performances in general, male and female comparisons lead to interesting observations. Due to certain physiological, anatomical, and personality differences, performances on certain tasks are favored for one sex over the other. However, an often under-played variable in task choice and accomplishments are social-cultural influences. Although physical fitness testing, reaction time data, and sports' records indicate the general superiority of males, females are demonstrating feats that surprise most people. For example, some of the women's records in track and field and swimming at the 1952 Olympic Games were better than the men's records fifty-two years earlier!

With greater social acceptance and encouragement, women can and are demonstrating skills fairly comparable with those exhibited by males. Naturally, there are those motor tasks typically associated with females at which they excel when compared to males. Nevertheless, present research in general indicates that sex differences in performance in varied motor tasks become more apparent with increasing age (Singer, 1969), in favor of the boys. Into adolescence and early adulthood, the separation between the sexes widens.

(17) *The aging process.* Various kinds of motor skills are affected in dissimilar fashion by the aging process. There are some vocational occupations and sports events that can be participated in successfully for a great duration of a person's life. Others, of course, cannot. Although the process of learning may be little affected by age, performance variables are, and they play an important role in output.

An older person needs more time to react; to perceive quickly and respond. When he can work at his own speed, and the task is self-paced (the response is initiated by the performer to a fixed stimulus rather than to some unpredictable stimulus) the individual is not handicapped. The increased inability to receive and transmit information is a symptom of older age. Also, tasks requiring large amounts of strength, endurance, speed, and flexibility work to his disadvantage. Complex motor tasks, with too much information in the display, may result in a tendency to pay attention to irrelevant information. All these considerations indicate the need to match the appropriate task with the aging person for best results.

These individual learner considerations by no means exhaust the list of possible variables, but they certainly should serve as warnings as to the complexity of the learning situation in the psychomotor domain. The task is now to interpret and identify the ways the learning process may be enhanced through the manipulation of environmental variables.

Psychomotor Learning: Background Material

Assuming the basis and validity of laws or principles of learning, the logical step is to use them in the psychomotor domain where applicable. Even research findings, not of sufficient quality and quantity to form the basis of a "principle" but strong enough to indicate a trend, constitute available support for action. Unfortunately, this "logical step" is not as easy as it sounds.

In the first place, acceptable principles of learning are usually so broad and generalizable as to constitute nothing more than the obvious. Secondly, there is question as to the practical application of more specific learning principles, formulated on a conceptual basis from laboratory work in artificial situations. Gagné (1962), for one, has raised serious doubts as to the usefulness of learning principles for the training of military skills. Thirdly, and of most frustration, is the diverse nature present research takes in the various areas concerned with the acquisition of motor skills.

On the last point, miniature models, nomenclature, and research projects in each area reflect the uniqueness of the matter dealt with. Can one tie together various approaches to the solution of how effective motor learning occurs? In the early portion of this century, behaviorists and gestaltists demonstrated distinct approaches to learning, formed unique terms, and emphasized different factors. This practice served at once to widen one's understanding of the learning process but at the same time to cause confusion. As theories developed each emphasized various aspects of learning. Problem-solving, the nature of the stimulus, perception, response, and the nature and effect of intervening variables were some of these sources of emphasis. What with the advent of mathematical models, neuro-psychological models, information theory, cybernetics, and man-machine dynamics, the problem has been magnified (Singer, 1966).

Military and industrial psychologists talk in terms of training factors. Knowledge of results, guidance and instructional techniques, cues in the display, task operations, and job analysis are of basic concern. Experimental psychologists still cling to concepts of conditioning. They are procedure and man-centered, studying such things as instructional methods, practice variations, habit formations, and hypothetical constructs called intervening variables. Those interested in operant conditioning and the Skinnerian approach emphasize reinforcement and the shaping of behavior. Information or communication theorists research the processing and transmitting of information. The standard reference is "bits," which refers to information the organism receives in a situation. Engineering psychologists stress task variables and closed loop servosystems, where the main interest is the difference between input-output and the nature of the transmission system. Cyberneticians compare man to a machine and provide a conceptual framework of control where feedback is of the utmost importance. Social psychologists analyze man's behaviors in terms of attitudes, values, social systems, and family and peer influences. Physical educators, home economists, vocational educators, and special educators glean odds and ends from all these approaches but generally adhere to guidelines suggested by educational psychologists. Thorndike-type laws, terms and research associated with the period *before* the 1940's and the accompaniment of an explosion of sophisticated learning models and designs generally make this group of educators "comfortable."

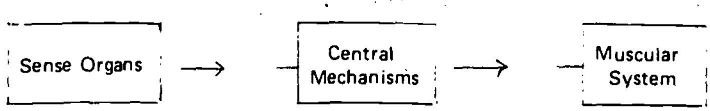
Each of the above-mentioned groups is interested in skill development and modification in the psychomotor domain. The accumulation, consolidation, and synthesis of behavioral "facts" from so many diverse approaches may be beyond reconciliation. Nevertheless, anyone concerned with behavior in the psychomotor domain in general should at least attempt to confront and resolve all these conceptual and experimental approaches. Certainly, Berelson and Steiner (1964) must be praised for their valiant effort to construct an inventory of scientific findings with regard to human behavior.

On the other hand, it can be legitimately argued that due to the unique complexities of each learning task area, research and theory should be developed and applied to the specific situation. The present trend toward the formulation of miniature models of learning, applicable to unique problems associated within the area of interest, contrasts with the original goals of psychologists to describe all of learning in one theory. An attempt at formulating a new taxonomy of human learning, with discussions on the problems relevant to the seven categories representing the various types of research, is presented by Melton (1964). In the psychomotor domain it may be necessary for the physical educator to attend to his own unique problems, the vocational specialist the same, and the military psychologist likewise. Much depends on the degree to which we believe in task-specificity, or, for that matter, the nature of the task (e.g., discrete, continuous, serial) as a consideration.

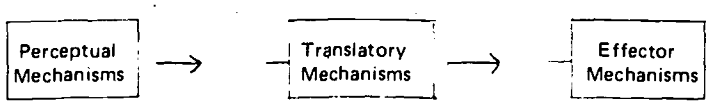
Signal detection, or vigilance, theory, was developed by military psychologists for situations pertinent to the military. In Swets' (1964) detection theory, human behavior in a variety of perceptual tasks is analyzed. Welford (1960) forwards the single-channel hypothesis as an explanation for the information processing of motor skills. Smith (1962) terms his cybernetic approach to the evaluation of man's behavior a neurogeometric theory. Poulton's (1954) model is geared for predictions in industrial work. Fitts (1964) favors an approach to studying motor learning that contains a framework of three types of models: communication, control system, and adaptive. Henry (1960), a physical educator, has proposed a Memory Drum Theory of Neuromotor Reaction, that deals with various aspects of motor performance. These represent but a sampling of diverse theoretical advancements to be applied to the learning and performing of motor skills.

Thus the problem of task-specific or area-specific research and theory versus a general domain approach is a real one. Evidently, those concerned with instructional settings must consider situational specific evidence, task-related information, as well as general behavioral knowledge. This will be the case in the next section of this paper, where a wide range of sources provide the general guidelines as to effective instructional settings in the psychomotor domain.

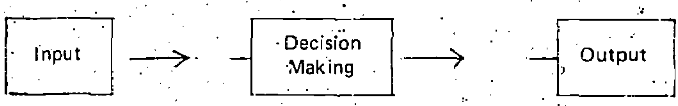
Before reporting and interpreting research findings, the general operational framework of the human in performance should be analyzed. The systems-analysis technique can be applied in an extremely general way for a better understanding of human activity. Thus far only learner characteristics have been discussed. From a physical point of view, the simple components involved in a learner's processing of and responding to information are as follows (Whiting, 1969):



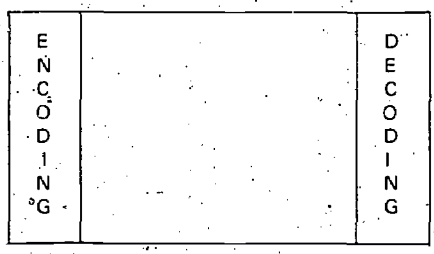
The Central Mechanisms are further divided by Whiting in terms of operations:



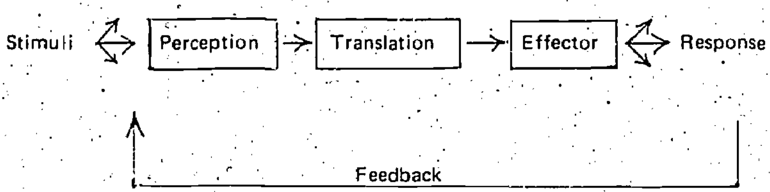
At the functional level, the human system is represented by Whiting as going through these processes:



Response activity to stimulation is diagramed in a similar manner by those who view the human organism as an information processing system. An individual receives a certain amount of information (S) in a situation. He has to transmit (T) this information and respond (R), but since no mechanism is perfect, information may be lost when encoding, transmitting, or decoding. Represented by diagram, the process would appear thusly (Singer, 1966):



Learner characteristics, e.g., sense acuity, stimulus selection (perception), abilities, skills, etc., will influence the effective processing of and reacting to information. From stimulation to response, a human partially functions according to the limitations of his systems. The other major consideration are situational variables (training, learning, practice, environmental display—as they are commonly referred to). The shape and nature of the stimulus and response, the manipulation of learning conditions, and the process of learning are for the most part, the focal points of trainers and educators. For example, the importance of feedback from internal or external sources is recognized by learning specialists as a prerequisite to the acquisition of skill. Hence, the learning-performance schema is further extended (Singer, 1966):



Instructional Settings

The approaches one employs in the learning process may depend to a fair extent on whether he views himself as an educator or trainer. In the psychomotor domain, there are those who consider themselves educators; others who refer to themselves as trainers. Actually, little real differences are noted between training and education. The objectives of both are to modify behavior, and both are a part of the instructional process. Instruction involves systematic, guided experiences similar to education and to training. However, dissimilarities do exist between these two methods.

Generally speaking, education is more concerned with individual differences; with long-range effects, often not measurable. Training encompasses teaching people similar operations and expecting uniform outcomes. That is, there is less respect for individual changes. There are more short-term goals in training programs, in a relative sense, than in education programs. When individuals are trained, they come to the program with a certain set of skills. The major objective is to advance most of them to a given level of skill at the end of a specified period of time. For further clarification of the training-education issue as well as research information on training techniques, books by Glaser (1962) and Holding (1965) are recommended.

The psychologist views training as the practical application of that which is known of learning phenomena. The study of processes associated with learning concerns researchers and theorists; the applied aspects of this study can be seen in industry, the military, and the gymnasium. It is often hard to separate the trainer and the educator, especially in an education institutional setting. The coach, the industrial technologist, the home economist, and such appear to be both trainers and educators. They work at the level of each individual but goals are usually short-ranged and specified.

Most of the programs in the psychomotor domain are probably training-oriented. ("Educators" in the psychomotor domain will find offense in that statement, I am sure. Hopefully they will only attack the statement, and not me!) Perhaps Schalock (1968, p. 11-15) goes too far in his statement on the matter, though. He writes of three classes of influence behavior in teaching, and labels these training, instruction, and enculturation. In application, "training refers to teaching in the psychomotor area, instruction to teaching in the intellectual area and enculturation to teaching in the attitudinal area." This over-simplication of the problem does not allow for the probability that instruction can and indeed does occur in the psychomotor domain. At any rate, the obvious intent of any training program is to reach short-term objectives in as short a period of time as possible with planned sequences of experience. The instructional setting thereby represents a combination and interaction of variables manipulated in such a way as to produce the desired output. It is these variables, contributing to the "intent" mentioned above, with which we will be concerned.

Gagné writes (1965):

> Instructing means arranging the conditions of learning that are external to the learner. These conditions need to be constructed in a stage-by-stage fashion, taking due account at each stage of the just previously acquired capabilities of the learner, the requirements for retention of these capabilities, and the specific stimulus situation needed for the next stage in learning. As a consequence, instruction is seen to be a very intricate and demanding activity.

In any learning situation, there are a host of external conditions that can be manipulated. Of first concern is the nature of the display.

(1) *Display.* The specific learning situation, or task, the individual is faced with is his display. In an experimental psychology laboratory experiment, the display is the equipment, cues, and task confronting the subject. In piloting a plane, it is represented by the flight conditions and response panel. The external information in a given situation, pertinent or non-pertinent to the task, represents the stimuli to which the organism will probably attend. The challenge in facilitating learning is to modify the display in such a way that desired outcomes are best met. The teacher or instructor is external to the subject's display, but serves as a potential display moderator or manipulator. Cues offered by the instructor can make the display easier to master for the learner.

(a) Merely changing the atmosphere from the previous practice can prove to induce sufficient improvement. The Hawthorne experiment, performed in the 1930's, is a classic example of this. Several secretaries were placed in rooms to work under various different working conditions. Light illumination was changed, and the girls were given free lunches, rest periods, and even allowed to go home early at times. Every time a change was made, for the better or worse, production improved. For example, when the rest periods were taken away, production still increased. Evidently, motivation was elevated with each situational change as the girls were reminded that someone was concerned with what they were doing. A variety of experiences and environmental modifications can remove boredom and induce attention and motivation.

The previous discussion indicates the social aspects of changes in the display. The physical lay-out, in terms of the placement and nature of cues, the means to obtain feedback, and the actual involvement of the learner (active or passive, guided or non-guided) is more fully documented in the literature on performance.

(b) With regard to cues, the *visual* aspects of the task display can be modified in numerous ways. At initial levels of motor learning, the visual modality is apparently of prime importance in contributing to success. When visual, verbal, and kinesthetic modalities are compared in early effect on skill acquisition, the visual sense is usually found to be most relevant. Therefore, anything the learner can contribute to the situation in already-developed visual abilities, e.g., spatial-orientation, depth-perception, (along with desirable specific modifications in the display) will be reflected in learning progress rates and achievement.

One of the problems a learner usually has when he confronts a new learning task, reasonably complex in nature, is to attend to too many cues or aspects of the situation. He does not *selectively attend* to the most relevant ones without experience and/or guidance. A variety of cues can be and is distracting. Also, many tasks require a continual selective cue discrimination process. A basketball player in the midst of a fast-break is bombarded with countless, ever-changing, potentially-influencing stimuli: The dribbling of the basketball, direction, awareness of the relative placement of opponents and teammates, the backboard, the rim, the spectators and noise, and the coach's screams constitute some major sources of input. Simultaneous attention to all these cues would obviously cause a break-down in performance. High-level performance is demonstrated in part by concentration on the important cues of the moment, disregard for irrelevant ones, and perceptual awareness of possible immediate changes in the situation.

How does one reach that point in skill attainment? A good starting point is to examine the scope of the complex activity and to identify parts (mini-displays) of it that can be acquired separately. Returning to the athlete, he must go through stages of mastering the skills that contribute to overall success. Consequently he learns to dribble the ball to the extent he can execute this act at a level not requiring conscious awareness. Shooting skills are perfected so that they are not disturbed by defensive maneuvers, off-balance positioning, crowd noise, and so on. Proficiency in mini-displays and combined display experience leads to overall competency.

A mini-display can be left as it is in the "real" situation or modified according to emphasized desirable cues. In summarizing research, it has been concluded (Singer, 1968):

> Oftentimes certain visual cues are emphasized or artificial ones introduced in order to promote the learning of various skills. Sport examples of the artificial visual cues are found in (1) basketball, where spots or marks on the backboard provide specific points at which to aim for backboard shots; (2) archery, where sometimes the point-of-aim method is employed (a marker placed before the target is sighted upon); and (3) bowling, where the spot method of aiming is often used (a spot placed on the alley is aimed at instead of the pins).
>
> Artificial visual cues are used either as an initial learning technique, to be disregarded later, or as a continual performance aid. Although research is scattered and inconclusive on the value of these techniques, it does appear as if many of them are of value in fulfilling certain objectives. Theoretically analyzing the problem, *specific and precise* visual cues are easier to attend to than general vague ones. Furthermore, *nearer* cues should be easier to aim for than those more removed. However, not all learners will benefit equally from the identical cues in the same task.

Most of the work in the arrangement of displays can be found in the industrial and aviational psychology literature. Simplifying displays and rearranging them so that the perceptual information is more obvious and easier to attend to naturally results in greater insight into the task. In a study by Belbin and Hill (1957), workers on complicated cloth weaves were subjected to special techniques of training. Essentially it was discovered that an inadequate number of visual cues were present in the task. By reconstructing the task so that the weaves were enlarged, the cues were more visible. With improvement in performance, the display was once again placed into its original dimensions. The efficiency of this technique was demonstrated in the study as well as some subsequent research.

(c) Besides the importance of cue arrangement in the display for understanding the task, *visual feedback* functions to motivate, reinforce, and direct behavior. In most tasks, a person can see how he has done. In other ones, visual feedback is withheld or distorted. As is the case with all forms of feedback, immediate and accurate returns are desirable. Visual task cues, when compared to verbal and kinesthetic ones under systems of withholding or emphasizing have often been found to be the most beneficial to skill acquisition. Therefore, motor tasks should contain visual information on performance returns (seeing the results of one's operations) as well as clear and specific visual cues for information processing.

(d) Finally, displays have been adapted from real situations to artificial ones. In many industrial, military, and vehicle operation tasks, equipment is expensive and an element of danger may be present. Simulated equipment permits the training of large numbers of individuals who otherwise might not have the opportunity to learn. Devices are thus made specially to simulate, to a certain extent, the actual performance conditions or, perhaps, to prepare the individual for the actual task via emphasized audio-visual or tactile and kinesthetic cues.

These devices have been categorized according to their primary functions. A *trainer* is usually used as an aid in prompting cues necessary for the learning of a skill. Films or specially designed equipment help the learner to gain greater insight into the nature of the real task, although they generally do not simulate it. The purpose of a *simulator* is to provide simulated practice on the skill in the way it is to be generally performed (e.g., see Travers, 1963). For instance, in many parts of the country it is impossible to play golf all year. However, the Electronic Golf Range, developed by Brunswick, provides realistic golfing conditions. Regulation woods, irons, and balls are used with this computerized apparatus, which simulates a golf course and true playing conditions. Golfers can improve their strokes, have the opportunity to play when outdoor weather does not permit it, and enjoy the competitiveness and reality of the golfing situation. Fake plane cockpits, automobile controls, and machinery displays may serve as simulators or trainers.

(2) *Practice considerations.* Not only can the display be manipulated to

the benefit of the learner, but practice conditions may be specified as well. There are so many variables that a mere brief description is all that is possible in this paper. Most of these considerations are "old-hat" to psychologists. That is, they have been investigated from angles throughout the century, theories have arisen, and still disagreement exists on many crucial issues. Generally, research indicates the following:

(a) A skill may be practiced continuously (*massed conditions*) or with rest pauses or interpolated skill learnings (*distributed practice*). For most skills, distributed practice exerts a more positive influence on performance than massed practice. This is evident, for although immediate skill acquisition is favored under distributed practice, tests of retention demonstrate little difference in performance between initially massed and distributed practice groups.

(b) *Practice* alone is not sufficient for improvement. Without *knowledge of results*, learner's *interest and attention*, *meaningfulness* of the task to the learner, *understanding of goals*, *intent* to learn, *readiness* to learn, and some degree of *relationship* of practice conditions to real conditions, practice for all practical purposes is wasted.

(c) *Overlearning*, or practicing past a criterion, results in better retention of that which has been learned.

(d) *Better learned skills* are less prone to be disrupted by manipulated environmental conditions. Varying instructional or stressful conditions are more influential during the initial and unstable stages of learning.

(e) *Positive reinforcement* is a form of reward and it increases the probability of the desired act to occur. Random reinforcement is a more effective continual form of motivation than constant reinforcement.

(f) Very high *motivation* impedes progress in complex tasks. Highest performance is attained by individuals with intermediate motivation or drive, and as tasks increase in complexity, individuals with moderate motivation do better. Evidently, there is an optimal motivational level for each task.

(g) Reasonably *hard, specific, but attainable goals* produce better performance than easy goals or a general goal to do one's best (Locke, 1968).

(h) Behavior is influenced by previous experiences. Greater resemblance between task elements, between their respective stimuli and responses, results in a greater amount of *positive transfer*. Transfer is influenced by such factors as amount of practice on the prior task, motivation to transfer skill, method of training, and intent to transfer.

(3) *Practice conditions*. The general practice considerations just mentioned, although based on research in the motor skills area, can also easily be applied to the learning of any matter. The list, of course, could be

extended considerably. Let us examine at more depth some of the unique conditions associated with motor skills.

(a) First of all, motor skills are usually *retained* better and longer than the learning of other matter. It could be because there are less competing responses for them, they are over-practiced, and they are more important and meaningful to the learner. When the motor skills to be learned become more abstract and non-meaningful, the retention curve resembles that of verbal or written matter.

(b) In the area of *knowledge of results* (or feedback), various kinds have been identified (see Figure 9). Information provided to the performer during and after his execution of an act, from internal and/or external sources, constitutes knowledge of results. Generally speaking, knowledge of one's performance outcomes may take two directions: as *action* feedback or *learning* feedback (Miller, 1953). Action feedback provides information on the adequacy of the individual's responses in the given situation but learning feedback goes a step further; it presumably enables the person to cope with the task more effectively. He actually learns how to adjust his responses in future similar situations.

The categories of knowledge of results (KR) enumerated by Holding (1965) in Figure 7 are most useful in understanding the various dimensions of KR. In realistic situations, the learner is provided with some form of *intrinsic KR* with regard to his performance. Proprioceptive activity and the tactile senses inform him as to "feel" of the response. Visual feedback indicates accuracy in accomplishment. *Artificial KR*, also referred to as *augmented KR*, is incorporated into the learning situation when special cues are

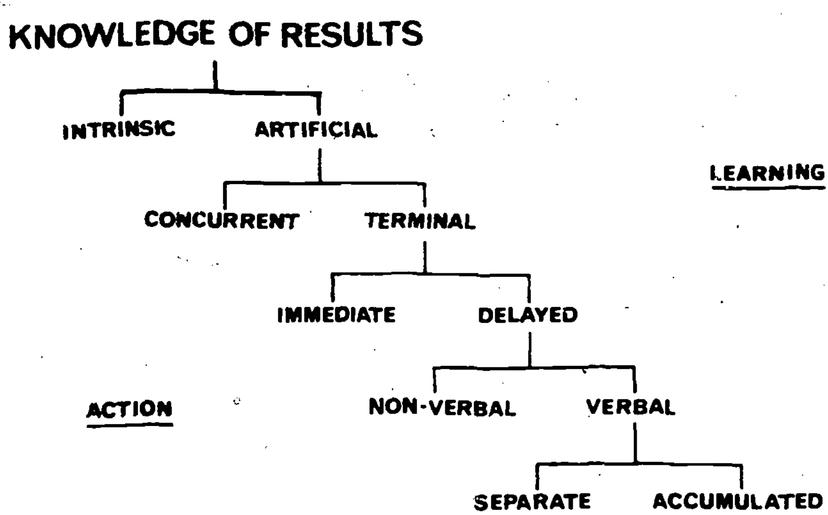


Figure 7. Different Kinds of Knowledge of Results. (From Holding, 1965).

added. Comments by an outsider or supplementary artificial visual and kinesthetic cues may facilitate the early acquisition of a skill. There is danger, however, in the learner relying too heavily on augmented KR. In the real task, once artificial KR is removed, the effects may be quite detrimental. Therefore, artificial information must be applied with caution, if it is to be used at all.

Artificial KR may be supplied during the task or at its completion. *Concurrent KR* and *terminal KR* are both useful sources of information to the learner. Assuming the value of immediacy in reinforcement, concurrent information should be of more value in some tasks, terminal KR in others. Much depends on the nature of the task. Although there is debate over the relative effects of various terminal delays in KR on performance, one conclusion appears to be sure: it must be provided before the next response is made, for most effective results. During concurrent KR, any delay will be disruptive. Hence, *immediate and delayed KR* must be considered in the context of concurrent or terminal feedback.

Verbal and non-verbal KR have been shown to improve skill acquisition. It was mentioned previously under the topic of "Display" that a comparison of kinesthetic, visual, and verbal cues usually leads one to place least importance on verbal cues of the three avenues of information feedback. Nevertheless, verbal comments serve to motivate, direct, and reinforce actions. The nature of verbal KR must be viewed in relation to the learning level of the individual and the complexity of the task.

(c) Various *guidance*, *demonstration*, and *instructional* techniques have been used in combination or alone in an attempt to improve the conditions under which one acquires motor skills. Verbal guidance is important for direction, although an early study and practical experience enables us to realize that too much talk or complex instructions will handicap learning in the initial stages. Manual guidance, or external manipulation of the passive learner on the part of the teacher, may prove beneficial. This procedure familiarizes the learner with appr... ses. It activates the proprioceptors involved ...ivity and provides the learner with a "feel" of the appropriate movement.

Demonstrations by experts, in person or on film, direct the learner to the desired objectives of the task. Seeing what is ultimately expected of the learner helps to yield mental images associated with motor performance. When objectives are clarified and specified, consequent attempts at attaining them become more purposeful and effective.

Instructional techniques encompass so many possibilities that it would be unreasonable to expect to do justice to them here. Nevertheless, the following include some of the variables of consequence in human performance.

Motion pictures, loopfilms, pictured representation of the task, video tape, tachistoscopes, and other visual aids have been employed in the research with varying degrees of success. Musical accompaniment to the learning and performance of industrial tasks and athletic skills have also yielded inconclusive effects on relaxation, motivation/stimulation, rhythm development, or for other specially designed purposes.

Whole and part techniques of instruction (practicing the task in its entirety or fractionating it for practice purposes) have influenced outcomes depending on the nature of the task. Recent efforts by Naylor and Briggs (1963) have helped to clarify the issue. They identify task complexity and task organization (interrelationship of parts) as dimensional considerations. One of the important conclusions is that tasks high in complexity and low in organization will be best favored under part-practice conditions and vice-versa.

Mental rehearsal (conceptualization, self-verbalization, mental practice, covert practice, mental imagery) of a motor skill has been verified through substantial research findings as an aid in learning.

The teaching of mechanical or other principles prior to task learning in the hope of generalizable transfer to situations where they are applicable has sometimes proven to be an aid; othertimes not. Consideration must be given to the learner's understanding and ability to apply these principles, among other factors.

In the area of bilateral transfer or cross-education, studies indicate the generalization effect of responses. For example, a limb trained in a task for learning or strength outcomes improves the performance of the "non-practiced" corresponding limb. The sequence or order in which tasks are learned may effect total performance outcomes, as is the case with verbal material. At least one researcher (Singer, 1968) dealing with realistic motor skills has not found the sequential order of learning tasks to make any appreciable difference. Also on the topic of transfer, intra-task difficulty has been investigated with conflicting results reported. Should individuals be taught a series of tasks leading from the simple to the most difficult or vice-versa? In an archery experiment, it was found that such progressions made little differential performance outcomes with college students (Singer, 1966).

Since most motor skills require speed and accuracy, these variables are of special concern when training students. It would appear that the oft-employed process of slowing down responses in order to concentrate on initial accuracy is a questionable procedure if both speed and accuracy are equally-contributing factors to proficiency. Practice should simulate actual conditions. Exceptions are made when the learner demonstrates a special need for a particular emphasis on one variable or the other.

One of the major broad issues is whether or not practice should proceed in a trial and error method or with errors minimized. There are those who believe the individual learns from his mistakes and that all possible responses, correct or incorrect, should be encouraged in a situation. Others uphold the Skinnerian approach in "shaping" behavior. Based on techniques employed in teaching machines or programmed texts, simple material is acquired first before the learner can go on to more complex endeavors. The learner cannot proceed until each step is mastered. Errors are omitted or at least minimized.

Researchers have compared traditional and programmed instructional differences in classroom settings where "academic" matter is learned. Usually, no performance distinctions are noted or else students subjected to programmed techniques fare better on written tests purported to measure content mastery. A much greater obstacle exists in attempting to design similar experiments in the psychomotor domain. How to program the learning of motor skills is a challenge to educators, trainers, and researchers. An attempt was made by Newman and Singer (1968) who found little performance differences in beginning tennis players taught by traditional and programmed procedures. However, it was speculated that with a longer duration of the experimental period, the programmed method might have proved to be more effective.

Theoretically, the issue is whether errors or inappropriate responses will be beneficial in the learning process, or detrimental, as they may be perpetuated and stabilized. Logical retorts could be offered in favor of either stand. Although one might not believe in too rigid an approach in trying to omit errors, Skinner's (1968) suggestion to teach the learner to discriminate between good and bad form before embarking on the task sounds reasonable. What follows is automatic self-reinforcement when desired responses occur. Furthermore, he states that reinforcement should be made immediately contingent upon successful responses. With the current enthusiasm in programmed techniques for written matter and numerous books on operant conditioning (a la Skinner) presently being published, such implications for motor learning should be seriously analyzed.

Future Directions.

The psychomotor domain is wide open for research to answer the many unresolved problems. Psychological literature is replete with verbal learning investigations and the study of lower forms of organisms. Satisfactory applicable research findings are needed to provide a better understanding of the learning process involved in the acquisition of motor skills used so often in daily routines.

For instance, information processing specialists have determined the number of "bits," or information, that can be handled or processed at one time with regard to written matter or stimuli offered through a particular sense modality. Knowledge of the channel capacity of a learner could certainly make motor learning more functional and efficient. If the channel capacity of the person learning a motor skill could be determined, the ideal amount of information would be presented to him at one time, resulting in the most productive learning situation.

Social situations cooperation, competition, and the presence of an audience exert influence on the acquisition of skill. Often motor learnings occur realistically in such settings. Working alone or in a teamwork operation may result in dissimilar performance.

The nature of psychomotor abilities and their relation to skill acquisition must be better defined. As Roberts (1968-69, p. 18) writes, "the available evidence tends to support the notion that relationships between abilities, learning performance, and the practice stage variable are multidimensional and therefore complex." Roberts, concerned with the practical applications of research primarily undertaken in the laboratory, asks a few questions that are pertinent here. Can a person's abilities be reliably and validly assessed? What abilities are needed for success in each task? Can weak abilities be identified, and can specialized training of a remedial nature improve the chances for succeeding in a given skill?

Certainly many other problematical areas can be identified and questions raised. The problems are great but not insurmountable. There is little doubt that media specialists will play a large role in the future in enabling learners of motor skills to gain more efficient and effective ways of reaching their goals. (1) They can provide the *ideal models* for the learner to emulate. (2) Task simulation will help those deficient in aspects of performance or those interested in maintaining performance levels. (3) Also, *cueing* prior to and during the execution of a skill or series of skills constitutes another possible function of media. These obvious services will hopefully be realized as well as the many untouched applications of media to the mastery of movement behaviors.

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The Classification of Educational Objectives In the Psychomotor Domain

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Three classification systems for educational objectives—one in the cognitive domain, a second in the affective domain, and a third in the psychomotor domain—have been developed as tools for writing and analyzing educational objectives. It must be emphasized that these are tools to be used *with educational objectives*. They were *not intended as tools for classifying behaviors* per se.

With respect to the psychomotor domain, some have tried to use the classification schema to classify all sorts of motor acts. There are systems for classifying motor acts and these are extremely valuable but the system presented in this chapter is for classifying *educational objectives* which emphasize some muscular or motor skill, some manipulation of material and objects, or some act which requires neuromuscular coordination. These objectives are stated in terms of abilities and skills.

There is a way in which the usefulness of the classification systems can be broadened. They *can* be employed in developing and analyzing *learning experiences* or *teaching strategies*. The classification systems were used in this way in a home economics curriculum development project at the University of Illinois.

Purposes of the Schema for Classifying Educational Objectives

The Taxonomy of Educational Objectives. Cognitive Domain (Bloom et al., 1956), provided for classification of educational goals which deal with the recall or recognition of knowledge and the development of intellectual abilities and skills. Briefly, the purposes of the taxonomy[1] as given by its originators are the following:

1. Bloom, Benjamin S., Max D. Engelhart, Edward Furst, Walter H. Hill, and David R. Krathwohl, *Taxonomy of Educational Objectives, Handbook I, Cognitive Domain*, David McKay Company, Inc., New York, 1956, pp. 1-3.

1. To help teachers, administrators, professional specialists and research workers who deal with curricular and evaluation problems to discuss their problems with greater precision;
2. To facilitate the exchange of information about curricular developments and evaluation devices;
3. To suggest the kinds of objectives that can be included in a curriculum;
4. To help teachers and others to gain a perspective on the emphasis given to certain behaviors by a particular set of educational plans;
5. To help curriculum builders to specify objectives so that it becomes easier to plan learning experiences and prepare evaluation devices.

The purposes of the taxonomy as set forth in the handbook on the cognitive domain are applicable to the classification systems for all of the domains. And, as was stated previously, the systems may be used in developing and analyzing learning experiences as well as objectives and, probably, could be applied to the development and analyses of content, teaching aids and facilities, and means of evaluation.

Need for Classification System for Educational Objectives, Psychomotor Domain

Those who proposed taxonomies of educational objectives for the cognitive and affective domains indicated that they had no special interest in the development of a classification system for educational objectives in the psychomotor domain. They stated that, "Although we recognize the existence of this domain, we find so little done about it in secondary schools or colleges, that we do not believe the development of a classification of these objectives would be very useful at present."[2] Later statements made by those who gave leadership to development of the first two taxonomies of educational objectives gave no evidence of a change in interest or intent with respect to development of the third.

Having made rather extensive use of the first two taxonomies of educational objectives, the author felt a serious lack in not having a classification system for educational objectives in the psychomotor domain for use in the development of curriculum materials and as a basis for evaluation of educational outcomes.

The psychomotor domain has relevance for education in general as well as for such areas of specialization as industrial education, agriculture, home economics, business education, music, art, and physical education. Educators in the field of vocational and technical education have a keen interest in a classification system for educational objectives in this domain because many technical jobs require a high degree of ability and skill in the psychomotor domain as well as in the cognitive and affective areas.

2. *Ibid.*, pp. 7-8.

A classification system for psychomotor objectives has all of the advantages of the classification systems for the other domains: it can be of use in research on teaching for the development of motor abilities and skills; teachers and curriculum makers can make use of it to communicate more easily with those they serve. Perhaps the greatest benefit lies in the rounding out of the three domains, thus permitting a more comprehensive study of the total field of objectives. A second order of benefits results from the ability to design educational programs which are sensitive to the full range of objectives impacting on the learner and the instructional setting.

Difficulties Inherent in the Task

Preliminary investigations with respect to the development of a classification system for educational objectives in the psychomotor domain led to the conclusion that there is a hierarchy among the three domains. The cognitive domain, though certainly very complex, is in a sense, somewhat "purer" than the other two domains. That is, cognition can take place with a minimum of motor activity. Also, feeling may not be greatly involved although it would seem reasonable to assume some degree of affect. The affective domain necessarily involves considerable cognition as well as feeling. And, the psychomotor domain, as implied in the very name, involves cognition and motor activity, as well as affective components involved in the willingness to act. The increasingly strong involvement of all three domains, from the cognitive to the affective to the psychomotor, results in a special problem of complexity in developing a classification system for this last domain.

Preliminary investigations also revealed another problem that of rendering the system taxonomic. A classification system that is not taxonomic would have merit in the study of educational objectives. But, one that is taxonomic should prove more valuable in determining the relative difficulty of achieving the objectives and as an aid in determining sequence of learning experiences. The problem was one of arriving at a basis for determining the relative difficulty or amount of skill involved in achieving educational objectives concerned with motor activity.

PROCEDURES

In developing the classification system for educational objectives in the psychomotor domain, the approach taken was an exploratory one. General procedures were outlined, but these were deliberately left flexible, accomodative, and "open."

The disadvantage of such an approach is the possibility of some loss of time and energy in pursuing the objective; that is, this approach may be somewhat lacking in efficiency. On the other hand, it avoids the narrow restrictiveness of a more cut-and-dried approach. It opens the way for the possibilities of greater creativeness.

Work undertaken during 1964-65 under a small grant from the Bureau of Educational Research, University of Illinois, consisted mainly of library research, conferences with scholars in educational psychology and the subject areas concerned with psychomotor objectives, and some analysis of motor activities related to educational objectives. Suffice to say, the work did give the investigator some confidence that the general procedural plan being followed might be a fruitful one. General procedures included the following:

1. A comprehensive review of related literature, especially of any that described ways of classifying psychomotor activities and, hence, suggested possibilities for classifying the educational objectives of this domain.
2. Collecting and analyzing the behavioral objectives of this domain as one way of gaining insight regarding a possible classification system.
3. Exploratory analyses of certain tasks to discover by observation and introspection the nature of the psychomotor activity involved. These analyses were carried out by the research assistants on the project who had read widely in the area before attempting the analyses.
4. Conferences with scholars who have specialized knowledge of the nature of psychomotor activity, development of classification systems for educational objectives, and of the areas of study where educational objectives in the psychomotor domain are of paramount concern.

From the beginning, it was readily apparent that, if the classification system were to be taxonomic in form, an "organizing principle" would have to be found. This question was one that the investigators kept in mind as work progressed.

Ascertaining what objectives "fit" in this domain was an early concern. The definition given in the *Taxonomy of Educational Objectives, Affective Domain*[3] served as a guide: Psychomotor objectives are those which "emphasize some muscular or motor skill, some manipulation of material and objects, or some act which requires a neuromuscular coordination."

Examples which were checked and approved by specialists in the subject fields involved, as belonging in the psychomotor domain, were:

Industrial Arts

1. To develop skill in precision surface grinding operations
2. To develop skill in setting-up and operating a production drill press

3. Krathwohl, David R., Benjamin S. Bloom, and Bertram B. Masia, *Taxonomy of Educational Objectives, Handbook II. Affective Domain*. David McKay Company, Inc., New York, 1964, p. 7.

3. To develop skill in setting-up and operating a production band saw

Agriculture

4. To develop skill in using an instrument similar to a syringe in penetrating a peach to extract a measured amount of juice and pulp to determine spray residue
5. To develop ability to pollinate an oat flower which involves using tweezers to open palea to place pollen on the stamen
6. To develop manipulative skill in debeaking a chick
7. To develop ability to place flowers on desired foundation based on a preconceived ideal with regard to a particular arrangement

Home Economics

8. To develop skill in draping material to fit a certain body proportion with a particular preconceived design
9. To develop skill in designing a flat pattern which can be used to make a garment
10. To develop ability to whip egg whites to their maximum volume

Music

11. To develop correct arm, hand, and finger positions in holding and playing a violin in response to aural cues
12. To develop ability of a student to play his part in a synchronized and balanced way with a group of students in the production of a piece of music
13. To develop ability in directing a musical group so that each movement has the same interpretation to each person in the group
14. To develop ability to produce the required amount of lip and breath control to achieve the desired duration, volume and character of a note on a French horn

Physical Education

15. To develop ability to maneuver and control one's body in propelling the body upward through the air as in high jumping
16. To develop ability to maintain proper stance and execute follow-through of movement after hitting a golf ball
17. To develop ability to draw a bow and hold that position while aiming arrow
18. To develop ability to throw a ball a desired distance to a desired place

Art

19. To develop ability to sketch a figure and costume it with the desired clothing design
20. To develop ability in manipulating a shuttle in weaving fabric on a loom

How the foregoing objectives are stated may concern some. Most are fairly broad and encompass a number of more limited behavioral objectives. The concern at this point was with defining clearly this domain of educational objectives; the examples contributed to the purpose.

It was not always an easy task to determine whether a given objective was *primarily* of one type (cognitive, affective, psychomotor) or another. One problem was related to *type* of *performance* called for in the objective. The concern of the project in developing the classification system was performance of a particular sort, that involving motor activity. But, performance may be almost wholly of a cognitive type and, although at this point of time with reference to the project it seems a bit strange, confusion sometimes resulted from uncertainty regarding the primary nature of the activity involved in an objective.

Another problem, one that is frequently encountered in analyzing educational objectives in all three domains, had to do with the lack of specificity of objectives as given in many curriculum guides. That is, many that certainly involved a great deal of motor activity, almost equally also involved the other domains. These were broad objectives, such as: Ability to give a successful party. Ability to conduct a meeting. Ability to conduct a play period for small children. The investigators finally concluded that these were in an "action-pattern" domain, hence beyond and encompassing the other three domains.

Certain definitions were arrived at as ones that would be useful in communicating regarding the psychomotor domain. These were as follows:

auditory pertaining to hearing or the sense or organs of hearing.
auditory cues volume, pitch, timbre, distance, pattern of sounds.
cues a stimulus which serves as a sign or signal of something else, the connection having been previously learned.
cue selection deciding what cues one must respond to in order to satisfy the particular requirements of task performance.
emotional set readiness in terms of attitudes favorable to the motor acts taking place.
fine motor acts those that are performed by small muscles, especially of the fingers, hand and forearm, frequently involving eye-hand coordination.
gross motor acts those involving the large muscle groups of the body, especially of the shoulders, trunk, and legs.
kinesthetic the muscle sense; pertaining to sensitivity from activation of receptors in muscles, tendons, and joints.
mechanism a habitual way of responding.
mental set readiness, in the mental sense, to perform a certain motor act.
perception the process of becoming aware of objects, qualities, or relations by way of sense organs.
physical set readiness in the sense of having made the anatomical and postural adjustments necessary for the motor act to take place.
psychomotor objectives those which emphasize some muscular or motor skill, some manipulation of material and objects, or some

act which requires a neuromuscular coordination. These objectives are stated in terms of abilities and skills.

readiness to respond set to produce an overt behavioral act.

reflex action an act, as a movement, performed involuntarily in consequence of a nervous impulse transmitted inward from a receptor, or sense organ, to a nerve center and outward to an effector, as a muscle or gland.

response overt behavioral act of an individual.

sensory stimulation impingement of a stimulus upon one or more of the sense organs.

set a preparatory adjustment or readiness for a particular kind of action or experience.

smell to perceive by excitation of the olfactory nerves.

smell cues (odors) ethereal, such as fruity, lemon; fragrance, as violet; burned, as tar; putrid, as bad fish; resinous, as pine; spicy, as cloves.

stimulus the source of energy which affects a sense organ; what the behavior is responding to in a situation.

tactile pertaining to the sense of touch.

tactile cues texture, temperature, shape, size, pressure, position, state of motion, weight.

taste ascertaining the relish or flavor by taking some into the mouth.

taste cues saltiness, sourness, bitterness, sweetness.

translation process process of relating perception to action.

visual concerned with the mental pictures or images obtained through the eyes.

visual cues color, spatial relations, shape (line, form, size), motion, light and shade.

Assistants on the project attempted to determine exactly what happens in what sequence when one is working toward the achievement of an objective in this domain. Two examples of the details of these efforts follow:

OBJECTIVE	SEQUENCE OF ACTION IN CARRYING OUT TASK
A. Ability to stack a tray.	1. Perception Visual, tactile and kinesthetic 2. Set 3. Response Readiness Selection of response Imitation Gross muscular activity 4. Mechanism response is learned 5. Complex overt response Resolution of uncertainty Automatic performance
B. Ability to carry a large tray.	1. Perception 1.12 Visual

2. Set
    2.10 Mental set
        2.11 Discrimination
    2.20 Physical set
        2.21 Receptor set
        2.22 Postural set
3. Response
    3.10 Readiness to respond
    3.20 Selection of response
        3.21 Imitation
        3.22 Trial and error
4. Mechanism—learned response
5. Complex overt response
    5.10 Resolution of uncertainty
    5.20 Automatic performance

As the described procedures were being carried out, a number of attempts at the development of a useable classification system were being made. Finally, a useable schema was achieved. Feedback from a number of interested persons after publication of the initial report in the *Illinois Teacher of Home Economics*[4] and presentation at a number of education conferences, in addition to conferences with some scholars not previously consulted, resulted in some revision of the schema and some thought as to possible further revision.

The present form of the classification system is herewith presented.

The Schema for Classifying Educational Objectives in the Psychomotor Domain

The major organizational principle operating is that of complexity with attention to the sequence involved in the performance of a motor act. That is, objectives that would be classified at the lower levels are less complex in nature than related objectives at upper levels. In general, they are easier to carry out. And, those at the upper levels build on those at the lower.

1.0 *Perception*—This is an essential first step in performing a motor act. It is the process of becoming aware of objects, qualities, or relations by way of the sense organs. It is a necessary but not sufficient condition for motor activity. It is basic in the situation-interpretation-action chain leading to motor activity. The category of perception has been divided into three subcategories indicating three different levels of the perception process. This level is a parallel of the first category, receiving or attending, in the affective domain.

1.1 *Sensory stimulation*—Impingement of a stimulus upon one or more of the sense organs.

4. Simpson, Elizabeth Jane, "The Classification of Educational Objectives, Psychomotor Domain," *Illinois Teacher of Home Economics*, Vol. X, No. 4, pp. 110-144.

1.11 *Auditory*–Hearing or the sense of organs of hearing.
1.12 *Visual*–Concerned with the mental pictures or images obtained through the eyes.
1.13 *Tactile*–Pertaining to the sense of touch.
1.14 *Taste*–Determine the relish or flavor of by taking a portion into the mouth.
1.15 *Smell*–To perceive by excitation of the olfactory nerves.
1.16 *Kinesthetic*–The muscle sense: pertaining to sensitivity from activation of receptors in muscles, tendons, and joints.

1.1 *Sensory stimulation*–Illustrative educational objectives.
Sensitivity to auditory cues in playing a musical instrument as a member of a group.
Awareness of difference in "hand" of various fabrics.
Sensitivity to flavors in seasoning food.

The preceding categories are not presented in any special order of importance, although, in Western cultures, the visual cues are said to have dominance, whereas in some cultures, the auditory and tactile cues may pre-empt the high position we give the visual. Probably no sensible ordering of these is possible at this time. It should also be pointed out that "the cues that guide action may change for a particular motor activity as learning progresses (e.g., kinesthetic cues replacing visual cues)."[5]

1.2 *Cue selection*–Deciding to what cues one must respond in order to satisfy the particular requirements of task performance. This involves identification of the cue or cues and associating them with the task to be performed.
It may involve grouping of cues in terms of past experience and knowledge. Cues relevant to the situation are selected as a guide to action; irrelevant cues are ignored or discarded.

1.2 *Cue selection*–Illustrative educational objectives.
Recognition of operating difficulties with machinery through the sound of the machine in operation.
Sensing where the needle should be set in beginning machine stitching.
Recognizing factors to take into account in batting in a softball game.

1.3 *Translation*–Relating of perception to action in performing a motor act. This is the mental process of determining the meaning of the cues received for action. It involves symbolic translation, that is, having an image or being reminded of something, "having an idea," as a result of cues received. It may involve insight which is essential in solving a problem through perceiving the relationships essential to solution. Sensory translation is an aspect of this level. It involves "feedback," that is, knowledge of the effects of the process. Translation is a continuous part of the motor act being performed.

5. Loree, Ray. Correspondence with investigator. June, 1965.

1.3 *Translation* – Illustrative educational objectives.
Ability to relate music to dance form.
Ability to follow a recipe in preparing food.
Knowledge of the "feel" of operating a sewing machine successfully and use of this knowledge as a guide in stitching.

2.0 *Set* – Set is a preparatory adjustment or readiness for a particular kind of action or experience.
Three aspects of set have been identified: mental, physical, and emotional.

2.1 *Mental set* – Readiness, in the mental sense, to perform a certain motor act. This involves, as prerequisite, the level of perception and its subcategories. Discrimination, that is, using judgment in making distinctions, is an aspect of mental set.

2.1 *Mental set* – Illustrative educational objectives.
Knowledge of steps in setting the table.
Knowledge of tools appropriate to performance of various sewing operations.

2.2 *Physical set* – Readiness in the sense of having made the anatomical adjustments necessary for a motor act to be performed. Readiness, in the physical sense, involves receptor set, that is, sensory attending, or focusing the attention of the needed sensory organs and postural set, or positioning of the body.

2.2 *Physical set* – Illustrative educational objectives.
Achievement of bodily stance preparatory to bowling.
Positioning of hands preparatory to typing.

2.3 *Emotional set* – Readiness in terms of attitudes favorable to the motor acts taking place. Willingness to respond is implied.

2.3 *Emotional set* – Illustrative educational objectives.
Disposition to perform sewing machine operation to best of ability.
Desire to operate a production drill press with skill.

3.0 *Guided response* – This is an early step in the development of skill. Emphasis here is upon the abilities which are components of the more complex skill. Guided response is the overt behavioral act of an individual under the guidance of the instructor or in response to self-evaluation where the student has a model or criteria against which he can judge his performance. Prerequisites to performance of the act are readiness to respond, in terms of set to produce the overt behavioral act and selection of the appropriate response. Selection of response may be defined as deciding what response must be made in order to satisfy the requirements of task performance. There appear to be two major subcategories: imitation and trial and error.

3.1 *Imitation* – Imitation is the execution of an act as a direct response to the perception of another person performing the act.

3.1 *Imitation* – Illustrative educational objectives.

Imitation of the process of stay-stitching the curved neck edge of a bodice.

Performing a dance step as demonstrated.

Debeaking a chick in the manner demonstrated.

3.2 *Trial and error*—Trying various responses, usually with some rationale for each response, until an appropriate response is achieved. The appropriate response is one which meets the requirements of task performance, that is, "gets the job done" or does it more efficiently. This level may be defined as multiple-response learning in which the proper response is selected out of varied behavior, possibly through the influence of reward and punishment.

3.2 *Trial and error*—Illustrative educational objectives.

Discovering the most efficient method of ironing a blouse through trial of various procedures.

Determining the sequence for cleaning a room through trial of several patterns.

4.0 *Mechanism*—Learned response has become habitual. At this level, the learner has achieved a certain confidence and degree of proficiency in the performance of the act. The act is a part of his repertoire of possible responses to stimuli and the demands of situations where the response is an appropriate one. The response may be more complex than at the preceding level; it may involve some patterning in carrying out the task.

4.0 *Mechanism*—Illustrative educational objectives.

Ability to perform a hand-hemming operation.

Ability to mix ingredients for butter cake.

Ability to pollinate an oat flower.

5.0 *Complex overt response*—At this level, the individual can perform a motor act that is considered complex because of the movement pattern required. At this level, skill has been attained. The act can be carried out smoothly and efficiently, that is, with minimum expenditure of time and energy. There are two subcategories: resolution of uncertainty and automatic performance.

5.1 *Resolution of uncertainty*—The act is performed without hesitation of the individual to get a mental picture of task sequence. That is, he knows the sequence required and so proceeds with confidence. The act is here defined as complex in nature.

5.1 *Resolution of uncertainty*—Illustrative educational objectives.

Skill in operating a milling machine.

Skill in setting up and operating a production band saw.

5.2 *Automatic performance*—At this level, the individual can perform a finely coordinated motor skill with a great deal of ease and muscle control.

5.2 *Automatic performance*—Illustrative educational objectives.

Skill in performing basic steps of national folk dances.
Skill in tailoring a suit.
Skill in performing on the violin.

6.0 *Adaptation* Altering motor activities to meet the demands of new problematic situations requiring a physical response.

6.0 *Adaptation* Illustrative educational objectives.
Developing a modern dance composition through adapting known abilities and skills in dance.

7.0 *Origination* Creating new motor acts or ways of manipulating materials out of understandings, abilities, and skills developed in the psychomotor area.

7.0 *Origination* Illustrative educational objectives.
Creation of a modern dance.
Creation of a new game requiring psychomotor response.

Application of the Schema to an Educational Problem

Following are some examples of educational objectives, all related to the problem of *learning to use the sewing machine in garment construction.* They progress from the simple to the more complex. Each objective has been classified with the taxonomy of educational objectives, psychomotor domain. *The list is not necessarily a comprehensive one for this particular problem.* Only those objectives that may be classified in the psychomotor domain have been included. Obviously, some of these might *also* be classified in the cognitive or affective domain; in analyzing such educational objectives, it will be helpful to indicate the appropriate category in each relevant domain.

Problem: Learning to Use the Sewing Machine in Garment Construction

I. Objectives at *1.0 Perception* level.

Recognition of the sound of a sewing machine that is operating properly and the sound of one with operating difficulties. (1.2 Cue selection.)

Sensing where the needle should be set in beginning machine stitching. (1.2 Cue selection.)

Ability to follow pattern directions and markings in sewing a garment. (1.3 Translation.)

II. Objectives at *2.0 Set* level.

Knowledge of procedures in starting and stopping a sewing machine. (2.1 Mental set.)

Knowledge of how to guide fabric in using sewing machine so that stitching is desired distance from the edge. (2.1 Mental set.)

Knowledge of how to thread machine. (2.1 Mental set.)

Knowledge of methods for finishing a line of stitches so that the stitches will hold. (2.1 Mental set.)

Knowledge of how and when to adjust tension and stitch length in doing machine stitching. (2.1 Mental set.)

Positioning of body and hands for conservation of energy and greatest efficiency in using the sewing machine. (2.2 Physical set.)

Disposition to perform sewing machine operation to best of ability. (2.3 Emotional set.)

III. Objectives at *3.0 Guided Response* level.

Imitation of procedures in threading sewing machine. (3.1 Imitation.)

Imitation of procedures in operating sewing machine with respect to starting, stitching, and stopping. (3.1 Imitation.)

Imitation of the process of stay-stitching a straight edge and a curved edge. (3.1 Imitation.)

IV. Objectives at *4.0 Mechanism* level.

Ability to thread a sewing machine correctly without hesitation. (4.0 Mechanism.)

Ability to operate a sewing machine smoothly in starting, stitching, and stopping. (4.0 Mechanism.)

Ability to finish a line of stitching so it will hold. (4.0 Mechanism.)

Ability to adjust length of stitch and tension without hesitation according to the requirements of the situation. (4.0 Mechanism.)

V. Objectives at *5.0 Complex Overt Response* level.

Proceeding with increased confidence in operating a sewing machine and performing in a coordinated way the various tasks that are involved in its operation. (5.1 Resolution of uncertainty.)

Skill in operating a sewing machine in constructing a garment. (5.2 Automatic performance.)

VI. Objectives at *6.0 Adaptation* level.

Adapting skills developed in using one type or make of sewing machine to the operation of another type or make. (6.0 Adaptation.)

Concluding Statement

The classification system for educational objectives in the psychomotor domain presented in this chapter has been tried successfully. It appears to work! Next steps include consideration of certain minor revisions in some of the subcategories and "fleshing out" the schema with further illustrations.

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The Structure and Measurement of Psychomotor Abilities: Some Educational Implications

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The contribution I feel best able to make to this conference is a description of our research on psychomotor skills over the past 18 years. Specifically, I will deal with several interrelated areas. The primary program to be discussed concerns the identification of psychomotor abilities accounting for individual differences in performance of a wide variety of psychomotor tasks. Within this program I will deal with a variety of ability areas ranging from fine manipulative performance to areas of gross physical proficiency. A second program area in our work deals with relationships between these abilities and the learning of more complex psychomotor skills. Within this second area we have dealt with a number of learning variables including amount of practice, transfer, and retention.

In describing our research it may be of particular interest to stress the definitions of the psychomotor abilities which have been derived from this research; to specify the kinds of tests and task materials utilized in these studies and to describe those found to best measure these abilities.

The specification of these abilities, measures, and materials have particular relevance to curriculum development in that they, (a) help specify the range of activities that need to be covered in order to be comprehensive in this area, (b) they specify measures for possible use in assigning or selecting students for particular training efforts or for evaluating progress and proficiency in various areas of psychomotor performance, and (c) they provide suggestions for materials and apparatus development for inclusion in particular psychomotor development and training activity.

Conceptual and Methodological Framework

First I would like to define some concepts which have been developed. I find it useful to distinguish between the concepts of "ability" and "skill." As we use the term, *ability* refers to a more general trait of the individual which has been inferred from the correlations obtained among performances of individuals on certain kinds of tasks. Some abilities (e.g., color vision) depend more on genetic than learning factors, but most abilities depend on both to some degree. In any case, at a given stage in life, they represent traits or organismic factors which the individual brings with him when he begins to learn a new task. These abilities are related to performance in a variety of human tasks. For example, the fact that spatial visualization has been found related to performance on such diverse tasks as aerial navigation, blueprint reading and dentistry, makes this ability somewhat more basic.

The term *skill* refers to the level of proficiency on a specific task or limited group of tasks. As we use the term skill, it is task oriented. When we talk about proficiency in flying an airplane, in operating a turret lathe, or in playing basketball, we are talking about a specific skill. Thus, when we speak of acquiring the skill of operating a turret lathe, we mean that this person has acquired the sequence of responses required by this specific task. The assumption is that the skills involved in complex activities can be described in terms of the more basic abilities. For example, the level of performance a man can attain on a turret lathe may depend on his basic abilities of manual dexterity and motor coordination. However, these same basic abilities may be important to proficiency in other skills as well. Thus, manual dexterity is needed in assembling electrical components, and motor coordination is needed to fly an airplane.

Implicit in the previous analysis is the important relation between abilities and learning. Thus, individuals with high manual dexterity may more readily learn the specific skill of lathe operation. The mechanism of transfer of training probably operates here. Some abilities may transfer to the learning of a greater variety of specific tasks than others. In our culture, *verbal* abilities are more important in a greater variety of tasks than are some other types of abilities. The individual who has a great many highly developed basic abilities can become proficient at a great variety of specific tasks.

Elsewhere (Fleishman, 1964; Gagne & Fleishman, 1959) we have elaborated our analysis of the development of basic abilities. This included a discussion of their physiological bases, the role of learning, environmental and cultural factors, and evidence on the rate of ability development during the life span. With this much conceptualization in mind, we can say that in much of our previous work one objective has been to describe certain skills in terms of these more general ability requirements.

Perhaps a not too extreme statement is that most of the categorization of human skills, which is empirically based, comes from correlational and factor-analysis studies. Many of these studies in the literature are ill-designed or not designed at all. This does not rule out the fact that properly designed, systematic, programmatic, correlational research can yield highly useful data about general skill dimensions. We can think of such categories as representing empirically derived patterns of *response consistencies* to task requirements varied in systematic ways. In a sense this approach described tasks in terms of the common abilities required to perform them. As an example, let us take the term "tracking," a frequent psychomotor behavioral category employed by laboratory and systems psychologists alike. But we can all think of a wide variety of different tasks in which some kinds of tracking are involved. Can we assume that the behavioral category of tracking is useful in helping us generalize results from one such situation to another? Is there a general tracking ability? Are individuals who are good at compensatory tracking also the ones who are good at pursuit tracking? Do people who are good at positional tracking do well with velocity or acceleration controls? What happens to the correlations between performances as a function of such variations? It is to these kinds of questions that our program was directed.

Part I. Identification of Psychomotor Ability Factors

In subsequent years we have conducted a whole series of interlocking, experimental, factor-analytic studies, attempting to isolate and identify the common variance in a wide range of psychomotor performances. Essentially this is laboratory research in which tasks are specifically designed or selected to test certain hypotheses about the organization of abilities in a certain range of tasks (see, e.g., Fleishman, 1954). Subsequent studies tend to introduce task variations aimed at sharpening or limiting our ability-factor definitions. The purpose is to define the fewest independent ability categories which might be most useful and meaningful in describing performance in the widest variety of tasks.

Our studies generally start with some gross area of human performance. Thus, we have conducted studies of fine manipulative performances (Fleishman & Ellison, 1962; Fleishman & Hempel, 1954a), gross physical proficiency (Fleishman, 1963, 1964; Hempel & Fleishman, 1955), positioning movements and static reaction (Fleishman, 1958a), and movement reactions (Fleishman, 1958b; Fleishman & Hempel, 1956).

Thus far, we have investigated more than 200 different tasks administered to thousands of subjects in a series of interlocking studies. From the patterns of correlations obtained, we have been able to account for performance on this wide range of tasks of a relatively small number of abilities. In subsequent studies, our definitions of these abilities and their distinctions from one another are becoming more clearly delineated. Furthermore, it is now possible to specify the tasks which should provide the best measure of each of the abilities identified.

There are about 11 psychomotor abilities and 9 abilities in the area of physical proficiency which consistently appear to account for the common variance in psychomotor tasks. Before turning to the physical proficiency area let me list some of these psychomotor abilities and describe some of the tasks which best measure each ability.

1. *Control precision.* The ability is common to tasks which require fine, highly controlled, but not over-controlled, muscular adjustments, primarily where larger muscle groups are involved (Fleishman, 1958b; Fleishman & Hempel, 1956; Parker & Fleishman, 1960). This ability extends to arm-hand as well as to leg movements. It is most critical where such adjustments must be rapid, but precise. Tasks which best measure this ability include the Rotary pursuit and Controls Adjustment tasks (Figures 1 and 2).

2. *Multilimb coordination.* This is the ability to coordinate the movements of a number of limbs simultaneously, and is best measured by devices involving multiple controls (Fleishman, 1958b; Fleishman & Hempel, 1956; Parker & Fleishman, 1960). The ability has been found general to tasks requiring coordination of the two feet (e.g., Figure 3, the Rudder Control Test), two hands (e.g., the Two Hand Pursuit and Two Hand Coordination Tests, Figures 4 and 5, respectively) and hand and feet (e.g., the Plane Control and Complex Coordination Tests, Figures 6 and 7, respectively).

3. *Response orientation.* This ability has been found general to visual discrimination reaction psychomotor tasks, involving rapid directional discrimination and orientation of movement patterns (Fleishman, 1957a, 1957b, 1958b; Fleishman & Hempel, 1956; Parker & Fleishman, 1960). It appears to involve the ability to select the correct movement in relation to the correct stimulus, especially under highly speeded conditions. Figure 8 illustrates the Discrimination task and Figure 9 shows the Multidimensional Pursuit task found to measure this ability.

4. *Reaction time.* This represents simply the speed with which the individual is able to respond to a stimulus when it appears (Fleishman, 1954, 1958b; Fleishman & Hempel, 1955; Parker & Fleishman, 1960). There are consistent indications that individual differences in this ability are independent of whether the stimulus is auditory or visual and are also independent of the type of response which is required. However, once the stimulus situation or the response situation is complicated by involving alternate choices, reaction time is not the primary ability that is measured. Figure 10 illustrates the basic reaction time device.

5. *Speed of arm movement.* This represents simply the speed with which an individual can make a gross, discreet arm movement where accuracy is not the requirement (Fleishman, 1958b; Fleishman & Hempel, 1954, 1955; Parker & Fleishman, 1960). There is ample evidence that this ability is independent of the reaction-time ability. Tasks such as Two Plate Tapping (Figure 11) where the plates are separated at least 12 inches, best measures this ability.

REPRESENTATIVE TESTS OF DIFFERENT PSYCHOMOTOR ABILITIES

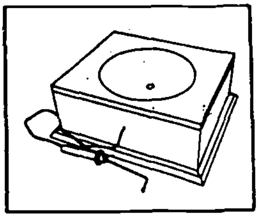

Figure 1. Rotary Pursuit

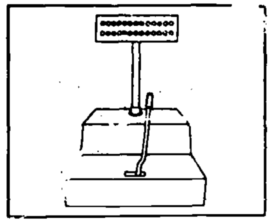

Figure 2. Controls Adjustment

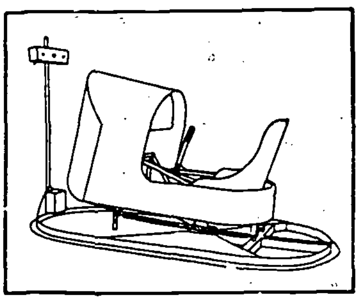

Figure 3. Rudder Control

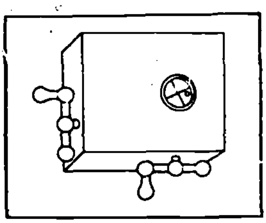

Figure 4. Two Hand Pursuit

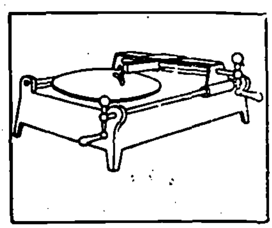

Figure 5. Two Hand Coordination

REPRESENTATIVE TESTS OF DIFFERENT PSYCHOMOTOR ABILITIES

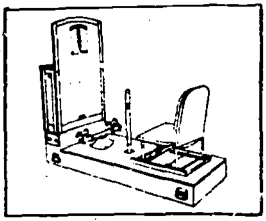

Figure 6. Complex Coordination

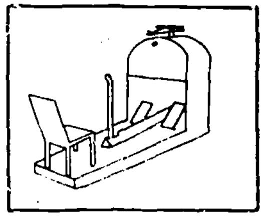

Figure 7. Plane Control

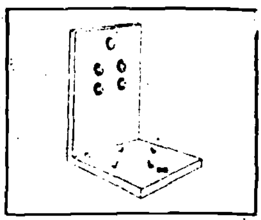

Figure 8. Discrimination Reaction Time

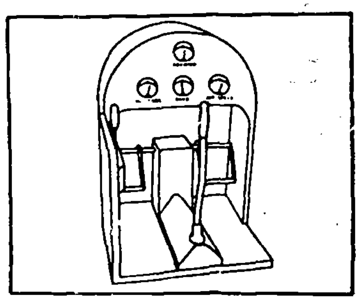

Figure 9. Multi-Dimensional Pursuit

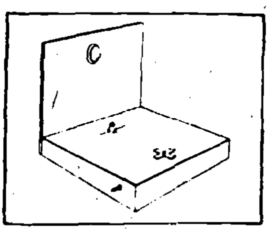

Figure 10. Reaction Time

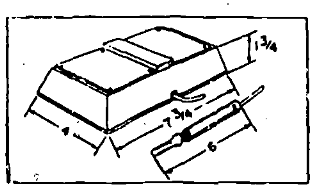

Figure 11. Two-Plate Tapping

6. *Rate control.* This ability involves the making of continuous anticipatory motor adjustments relative to changes in speed and direction of a continuously moving target or object (Fleishman, 1958b; Fleishman & Hempel, 1955, 1956). This ability is general to tasks involving compensatory as well as following pursuit, and extends to tasks involving responses to changes in rate. Our research has shown that adequate measurement of this ability required an actual response in relation to the changing direction and speed of the stimulus object, and not simply a judgment of the rate of stimulus movement alone. Figures 12, 13 and 14 respectively illustrate the Single Dimension Pursuit, Rate Control and Motor Judgement tasks, which measure this ability.

7. *Manual dexterity.* This ability involves skillful, well directed arm-hand movements in manipulating fairly large objects under speeded conditions (Fleishman, 1953b, 1954; Fleishman & Hempel, 1954b; Fleishman & Ellison, 1962; Parker & Fleishman, 1960; Hempel & Fleishman, 1955). The best generally available measures include the Minnesota Rate of Manipulation Tests (Figure 15), but there are newer experimental tasks which provide better measures.

8. *Finger dexterity.* This is the ability to make still-controlled manipulations of tiny objects involving, primarily, the fingers (Fleishman, 1953b, 1954; Fleishman & Hempel, 1954a; Parker & Fleishman, 1960; Hempel & Fleishman, 1955; Fleishman & Ellison, 1962). Tests like the Purdue Pegboard and O'Connor Finger Dexterity (see Figures 16 and 17) provide good measures.

9. *Arm-hand steadiness.* This is the ability to make precise arm-hand positioning movements where strength and speed are minimized; the critical feature, as the name implies, is the steadiness with which such movements can be made (Fleishman, 1953b, 1954, 1958a, 1958b; Fleishman & Hempel, 1955; Hempel & Fleishman, 1955; Parker & Fleishman, 1960). The ability extends to tasks requiring steady movements or holding steady limb positions (see Figures 18, 19, 20).

10. *Wrist-Finger Speed.* This ability is of limited generality and is best measured by printed tests requiring rapid tapping of the pencil in relatively large areas. (Fleishman, 1954a; Fleishman & Hempel, 1954a; Fleishman & Ellison, 1962). Pendular and/or rotary wrist movements may be involved. Figure 21 shows typical page sections of tests used to measure this ability.

11. *Aiming.* This ability appears to be measured by printed tests requiring the rapid placing of dots in very small circles, under highly speeded conditions (Fleishman, 1953, 1954a; Hempel & Fleishman, 1955; Fleishman & Ellison, 1962). See Figure 22.

Of course, there are detailed descriptions of the operations involved in each ability category; some of them are more general in scope than others. But it is important to know, for example, that it is not useful to talk about strength as a single dimension; rather, in terms of what psychomotor

REPRESENTATIVE TESTS OF DIFFERENT PSYCHOMOTOR ABILITIES

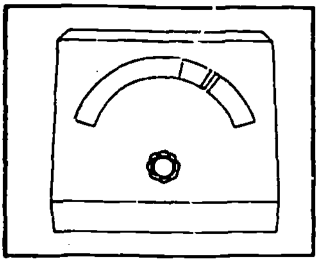

Figure 12. Single Dimensional Pursuit

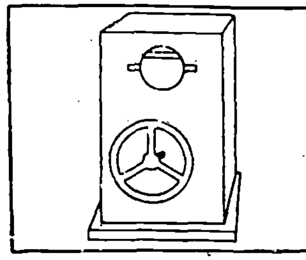

Figure 13. Rate Control

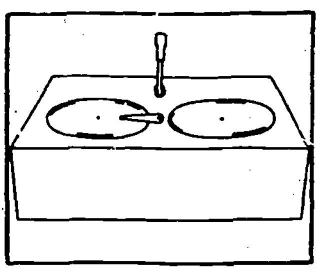

Figure 14. Motor Judgment

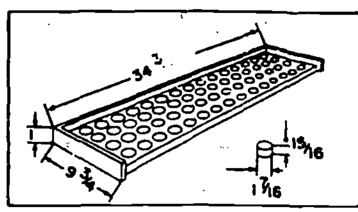

Figure 15. Minnesota Rate of Manipulation

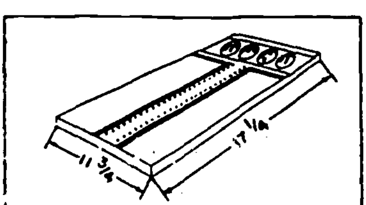

Figure 16. Purdue Pegboard

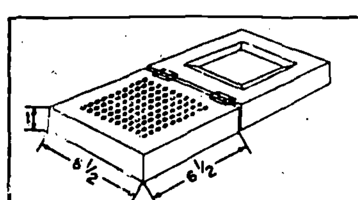

Figure 17. O'Conner Finger Dexterity

REPRESENTATIVE TESTS OF DIFFERENT PSYCHOMOTOR ABILITIES

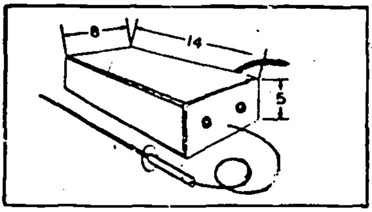

Figure 18. Precision-Steadiness

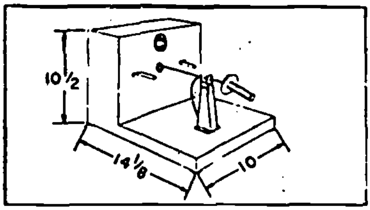

Figure 19. Steadiness-Aiming

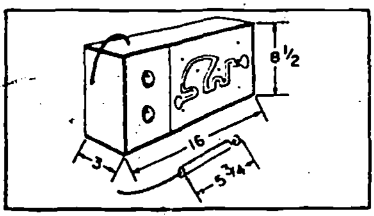

Figure 20. Track Tracing

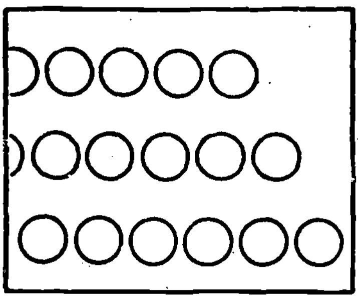

Figure 21A. Medium Tapping

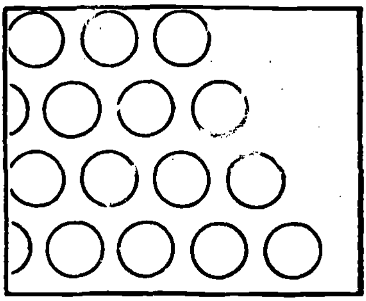

Figure 21B. Large Tapping

REPRESENTATIVE TESTS OF DIFFERENT PSYCHOMOTOR ABILITIES

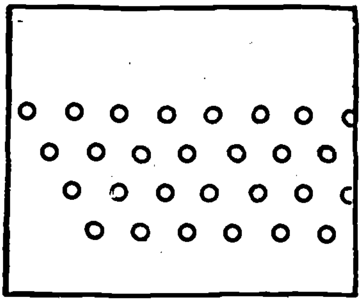

Figure 22A. Aiming

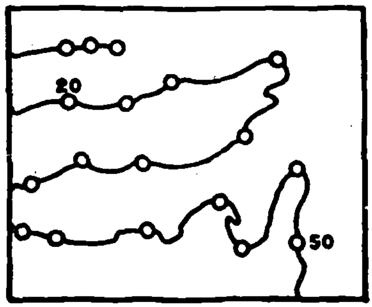

Figure 22B. Pursuit Aiming

tasks the same people can do well, it is more useful to talk in terms of at least four general strength categories which may be differentially involved in a variety of physical tasks.

Perhaps it might be useful to provide some examples of how one examines the generality of an ability category and how one defines its limits. The definition of the Rate Control ability may provide an example. In early studies it was found that this ability was common to tracking tests requiring one to follow a moving target (following pursuit tasks) as well as to tasks requiring one to keep a target points centered (compensatory pursuit tasks). To test the generality of this ability, tasks were developed to emphasize rate control ability, which were *not* conventional tracking tasks (e.g., controlling a ball rolling through a series of alleyways). The ability was found to extend to such tasks. Later studies attempted to discover if emphasis on this ability is in judging the rate of the stimulus as distinguished from ability to respond at the appropriate rate. A task was developed involving only button pressing in response to judgements of moving stimuli. (See Figure 23). Performance on this task did *not* correlate with other rate control tasks. Finally, several motion picture tasks were adapted in which the individual was required to extrapolate the course of a plane moving across a screen. The only response required was on an IBM answer sheet. These tasks did not relate to the core of tasks previously found to measure "rate control." Thus, our definition of this ability was expanded to include measures beyond conventional "pursuit" tasks, but restricted to tasks requiring the *timing of a muscular adjustment* to the stimulus change.

A similar history can be sketched for each ability variable identified. Thus, we know that an individual must have a feedback indicator of how well he is coordinating before the Multilimb Coordination ability is measured; we know that by complicating a simple *reaction-time* apparatus, by providing additional choice reactions, we measure not operation time but a separate ability (Response Orientation); however, varying the stimulus modality in a simple reaction-time device results in the measurement of the same ability of reaction time and does not result in measurement of a separate ability.

Some later studies using experimental-correlational approaches provided encouraging results which indicate that it is possible to build up a body of principles through systematic studies of ability-task interaction in the laboratory (Fleishman, 1956). The approach is to develop tasks which can be varied along specified physical dimensions; to administer these tasks, systematically varied along these dimensions, to groups of subjects who also receive a series of "reference" tasks, known to sample certain more generalized abilities (e.g., "Spatial Orientation," "Control Precision," certain "Cognitive Abilities"). Correlations between these reference tasks and scores on variations of the criterion task specify the ability requirements (and changes in these requirements) as a function to task variations. Thus far we have studied tasks varied along the following dimensions, (a) degree of rotation of display panels relative to response panels, (b) the predictability or non-predictability of target course or response requirements, (c) the extent to which the task allows the individual to assess the degree of coordination of multiplelimb responses, (d) the degree of stimulus-response compatibility in display-control relationships, (e) whether there is a

REPRESENTATIVE TESTS OF DIFFERENT PSYCHOMOTOR ABILITIES

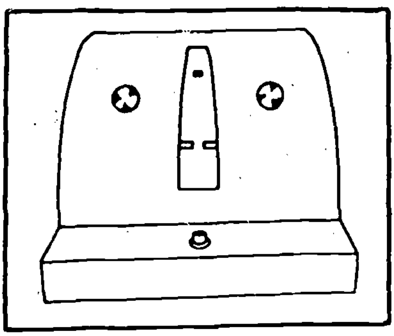

Figure 23. Visual Coincidence

constant "set" or changing "set" from one stimulus presentation to the next, (f) whether or not certain kinds of additional response requirements are imposed in a visual discrimination reaction task, (g) whether or not certain kinds of feedback are provided. Hopefully, once such principles are established, it should be possible to look at new tasks, operational or otherwise, and specify the ability requirements.

Part II. Research on Physical Fitness Dimensions and Measurement

We turn now to a more intensive look at our research on a special class of motor performance, that of physical proficiency. We will describe this area of our motor ability work in more detail because physical fitness programs are already an integral part of school curricula.

Literature Integration. As the first phase in this line of work, we conducted a comprehensive review of the literature on previous and currently used physical fitness tests. The literature in this area is replete with terms like "velocity," "speed," "explosive and static strength," "muscular endurance," "stamina," etc. Are these useful categories? Which categories of performance represent essentially different abilities and tests to measure them. The primary objective of this review was to examine the correlations found among such tests and to describe the factors they are presumed to measure. Special emphasis was placed on reviewing previous factor analysis studies of physical fitness tests in order to compile a comprehensive catalog of tests according to the abilities they seemed to measure (Fleishman, 1964a). It was possible to integrate these abilities into a meaningful schema and the main conclusion was that commonly used test batteries do not cover the range of possible fitness ability and many of the tests which are used overlap with one another in the ability measured. Fourteen possible abilities were described and questions were raised about other possible abilities.

The Experimental Studies. Considerable pre-testing of more than 100 tests was carried out with the objective of providing better measures of the abilities hypothesized from the literature review and other sources. The more reliable tests from these pre-tests were included with more familiar tests in two large scale studies with United States Navy recruits. The design of these studies allowed for the confirmation or redefinition of the hypothesized abilities as well as for the isolation of new abilities. Testing teams, under the supervision of the Yale University project, were established at the Great Lakes Naval Training Center, Illinois and at the San Diego Naval Training Center, California. At Great Lakes, 30 tests designed to measure different abilities in the areas of strength and endurance were administered; at San Diego, 30 tests in the areas of flexibility, balance, speed, and coordination were administered. At each Center all the tests were administered to more than 200 Navy recruits. Correlations among all these tests and background variables were obtained and subjected to factor analysis studies. Where previous factor analytic studies had focused on relatively small test batteries, here it was possible to combine alternative measures of practically all previously identified abilities within these two large scale studies. Both of these studies provided better definitions of the abilities that need to be assessed for a more comprehensive evaluation of physical proficiency and provided recommendations for tests more diagnostic of these different abilities. In all, it was possible to explain the correlations among these 60 different tests in terms of 11 primary abilities. A few of these abilities were quite specific (e.g., those confined to balancing weights) and were not considered further, but the more general ones were retained for further study.

To illustrate the research strategy let us examine more closely the design of the study to identify ability factors in the area of strength. Figure 24 lists the experimental and existing tests utilized in the study. Tests were chosen so that some emphasized flexor and other extensor muscles, some emphasized leg and others arm or trunk strength, some emphasized short and long runs. Others emphasized continuous, repeated, or minimal strain, some were timed or untimed. The design made it possible to examine the correlations among tests given to the same subjects to answer questions such as the following: Do we get two abilities separating flexor or extensor muscles? Is there a general strength ability common to all these tasks? Does prolonged strain on muscles (pull-up, push-ups) introduce a new ability (e.g., endurance), compared with tasks using the same muscles in a shorter but speeded period (Do as many push-ups as possible in 20 seconds)? Are there abilities common to muscle groups (arms vs legs) as distinguished from abilities dependent on the pattern of activity? What is the role of strength in running tasks? Figure 25 shows the possible ability factors that could have been obtained when we examined the actual relations among performances.

A similar design was followed in the areas of speed, flexibility, coordination and balance. The intercorrelations may be seen elsewhere (Fleishman, 1964). For the present we will merely summarize the abilities that emerged from these studies and the tests which had the highest factor loading (correlations with that ability). By examining the tests which grouped together on the same ability it was possible to define the abilities. The abilities identified and the test found to best measure each ability are as follows:

1. *Extent Flexibility:* Ability to flex or stretch the trunk and back muscles *as far as possible* in either a forward, lateral, or backward direction.

Extent Flexibility Test: (Originally called Twist and Touch). The subject stands, with his left side toward the wall, and arm's length away from the wall. With feet together and in place, he twists

	Possible Primary Factors									Possible General Factors				
	Dynamic Strength Arms		Dynamic Strength		Endurance			Explosive Strength						
	Flex.	Ext.	Legs	Trunk	Dyna-mic	Static	Runs	Arms	Legs	Dynamic Strength	Static Strength	Explosive Strength	Arm Strength	Leg Strength
1. Leg Lifts			x							x				
2. Push-ups (in 15 sec.)		x								x			x	
3. Reverse Sit-ups				x						x				
4. Deep Kneebends			x							x				x
5. Sit-ups				x						x				
6. Squat Thrusts			x							x			x	
7. Pull Weights	x									x	x		x	
8. Hand Grip											x			
9. Push Weights-Arms		x								x	x		x	
10. Arm Pull-Dyna.											x		x	
11. Push Weights-Feet			x							x	x			x
12. Trunk Pull-Dyna.											x			
13. Rope Climb	x									x			x	
14. Dips (in 10 sec.)		x								x			x	
15. Vertical Jump									x			x		x
16. Dips (to limit)		x			x					x			x	
17. Standing Broad Jump									x			x		x
18. Leg Raiser				x		x				x				
19. 10 Yard Dash							x		x			x		x
20. Bent Arm Hang	x					x				x			x	
21. 50 Yard Dash							x		x			x		x
22. Chins (to limit)	x				x					x			x	
23. Shuttle Run							x		x			x		x
24. Chins (in 20 sec.)	x									x			x	
25. Medic. Ball Put (Stand.)								x				x	x	
26. Hold Half Sit-up				x		x							x	
27. Medic. Ball Put (Sit.)								x				x	x	
28. Hold Half Push-up		x				x				x			x	
29. Softball Throw								x				x	x	
30. Push-ups (to limit)		x			x					x			x	

Figure 24. Possible Strength Hypothesize in the Experimental Strength Tests

back around as far as he can, touching the wall with his right hand at shoulder height.

2. *Dynamic Flexibility*. The ability to make repeated, *rapid*, flexing movements in which the resiliency of the muscles in *recovery* from strain or distortion is critical.

Dynamic Flexibility Test: (Originally called Bend, Twist and Touch). With his back to the wall and hands together, the subject bends forward, touches an "X" between his feet, straightens, twists to the left and touches an "X" behind him on the wall. He repeats the cycle, alternately twisting to the right and to the left, doing as many as possible in the time limit.

3. *Explosive Strength*. The ability to expend a maximum of energy in one or a series of explosive acts. This factor is distinguished from other strength factors in requiring mobilization of *energy* for a burst of effort, rather than continuous strain, stress, or repeated exertion of muscles. The two tests chosen to represent this factor emphasize different specific activities.

a. *Shuttle Run Test:* Twenty yard distance, covered 5 times, for 100 yard total.
b. *Softball Throw Test:* The subject throws a 12 inch softball, as far as possible without moving his feet.

4. *Static Strength*. The maximum *force* which a subject can exert, for a brief period, where the force is exerted continuously up to this maximum. In contrast to other strength factors, this is the force which can be exerted against external objects (e.g., lifting heavy weights, pulling against a dynamometer), rather than in supporting or propelling the body's own weight.

Hand Grip Test: The subject squeezes a Narragansett Company grip dynamometer, as hard as possible.

5. *Dynamic Strength*. The ability to exert muscular force *repeatedly* or continuously over time. It represents muscular-endurance and emphasizes the resistance of the muscles to fatigue. The common emphasis of tests measuring this factor is on the *power* of the muscles to propel, support, or move the body repeatedly or to support it for prolonged periods.

Pull-Ups Test: The subject hangs from bar with palms facing his body, and does as many pull-ups as possible.

6. *Trunk Strength*. This is a second, more limited, dynamic strength factor specific to the trunk muscles particularly the abdominal muscle.

Leg Lifts Test: While flat on his back, the subject raises his legs to a vertical position and lowers them to the floor as many times as possible in the time limit.

7. *Gross Body Coordination*. Ability to coordinate the simultaneous actions of different parts of the body while making gross body movements.

Cable Jump Test: The subject holds, in front of him, a short rope held in each hand. He attempts to jump through this rope without tripping, falling, or releasing the rope.

8. *Gross Body Equilibrium.* The ability of an individual to maintain his equilibrium, despite forces pulling him off balance, where he has to depend mainly on non-visual (e.g., vestibular and kinesthetic) cues.

Balance A Test: Using his preferred foot, and keeping his hands on his hips, the subject balances for as long as possible on a ¾ inch wide rail.

9. *Stamina.* The capacity to continue maximum efforts, requiring prolonged exertion over time. This factor has the alternate name of "cardiovascular endurance."

600 Yard Run-Walk Test: The student attempts to cover a 600 yard distance in as short a time as possible.

The National Study. The next step in this program was to establish *standards* for evaluating the performance of *individual* boys and girls on the separate tests. Tests found to be most reliable and diagnostic of the different ability factors were assembled into "batteries" and administered to high school students throughout the country.

In all, 14 tests found to cover 9 basic abilities were administered to more than 20,000 boys and girls, between the ages of 12 and 18, in 45 cities throughout the United States. (The list of cities and description of the cross-sections achieved is presented elsewhere) (Fleishman, 1964a). This phase produced the norms (percentile tables) for these tests, as well as developmental curves showing changes with age on the different physical fitness components for the 14 tests. Finally, 10 tests were recommended as the most efficient and reliable for measuring the 9 basic abilities. These tests have been called the *Basic Fitness Tests* and are illustrated in Appendix A.

Norms and developmental curves for these tests may be found elsewhere (Fleishman, 1964a, 1964b). Additionally, a record keeping system, called the Performance Record (Fleishman, 1964c) was developed to provide fitness profiles, conversions of raw scores to percentiles, a "fitness index," and the plotting of progress as a function of conditioning programs.

Summary of findings and implications. The fruits of this research program are of several sorts. First, we have a better understanding of the structure of the physical fitness area—the dimensions which best describe the variety of performance called for by the plethora of available physical fitness tests. It is seen that a relatively small number of such dimensions (or abilities) account for these diverse performances. In this sense the program was scientifically useful in bringing additional order to this field and in simplifying our descriptions of what needs to be measured in this area.

1. These results confirm that "physical proficiency" is not a single general ability; rather physical proficiency can best be described in terms of a number of broad, relatively independent abilities. The same individuals may be high on some abilities and low on others. In these terms, the more abilities an individual scores high on, the more "physically fit" he can be said to be. The results also allow more precise definition of each ability than was possible before.

2. A second category or results includes the many specific facts discovered about the nature of physical proficiencies and their interrelationships. For example, we now better understand the role of muscular endurance in strength tests, the relations between capacities of flexor and extensor muscles, and the primary abilities that account for running speed. Also confirmed is the distinction between two primary flexibility abilities and the generality of static strength across different muscle groups.

The "developmental curves" derived from the research are additional results in this second category. These curves show the rate of "growth" of the different physical proficiencies from age to age (Fleishman, 1964a). It was found that the curves for girls differed in form from those for boys in showing more marked developmental stages. For the boys the shapes of most curves were similar, but there were different critical ages at which the curves leveled out, depending on the ability measured.

Especially illuminating were the detailed analyses of strength tasks. Any characterization of individual strength which ignores one or more of the four strength abilities identified is incomplete.

Since several abilities were found to extend across different muscle groups (e.g., limbs and trunk), this points up the importance of "central" factors in physical fitness in addition to those reflected in the specific muscle apparatus. Such central factors include central nervous system involvement, responses to kinesthetic feedback mechanisms, heart and circulatory system development, general energy level, etc.

3. A third category of results of this research relates to specific fitness measurement principles discovered. We now know that variations in test procedure produce given variations in the fitness factors measures and in the reliability of the measure. For example, (a) speeded administration (times) of a Dynamic Strength test reduces its "purity" and brings in a second ability factor (Explosive strength); (b) longer Shuttle Run tests are more reliable than shorter ones in use; (c) simple dynamometer tests are preferred (over weight lifting tests) as measures of Static Strength; (d) a Gross Body Equilibrium ability factor is best measured by one-foot, rail standing tests with the eyes closed; (e) a Leg Lifts test is more valid and reliable than Sit-ups for measuring Trunk Strength.

4. A fourth major kind of outcome was the specification of the most efficient, practical, and reliable tests for measuring each ability and their assembly into a battery of *Basic Fitness Tests*. This battery, which will

undoubtedly be further improved by additional research, is based on our present state of research knowledge. A major phase of this work was the development of normative standards for the tests on a much larger national sample than has been possible heretofore. Simplified interpretative tables were provided for ages 12 through 18. Improved methods of evaluating and interpreting individual performances were developed, using modern measurement principles. These included forms of profile analysis, computation of a simplified Fitness Index, and evaluation of the rate of progress.

5. There are, of course, still many unanswered questions. Some of the most intriguing questions concern the nature of "coordination" and "agility." A concerted effort needs to be made to see if these are usefully considered "separate" abilities or if we can account for such performances in terms of the abilities already identified. Additional studies would involve a greater variety of "coordinated" performances than it has been possible to include so far. The use of our battery of tests, in the same study with these complex tests, should allow us to specify how much of the variance in such performances we still need to explain. At present, a Multilimb Coordination ability appears distinct from any Gross Body Coordination. The former is involved in perceptual-motor tasks involving simultaneous use of multiple controls (feet-hand, two-hand, two-feet), where the subject is typically seated. The latter appears to require movement of the entire body.

There is a need to use these tests to predict more complex skilled performances. This would tell us what portion of such performances are specific to the individual skills and how much is relatable to the physical fitness factors identified in our present program. There is also the practical question of how valid our tests are in predicting performance in complex jobs involving physical skills.

6. We also need to know more about the trainability of these component abilities and the degree of transfer of training across tasks representing the same abilities. We would expect high transfer between tasks on the same ability and low transfer between ability. A more interesting question is the amount of transfer of training from these ability components to more complex skilled performances.

Part III. Studies of Skill Learning

Effects of Practice. For a number of years, we have been interested in the relations between reference ability measures, developed around our perceptual-motor taxonomy, and a variety of learning phenomena (Fleishman & Hempel, 1954b; Fleishman & Hempel, 1955; Fleishman, 1957a; Fleishman, 1960a; Fleishman & Rich, 1963). Our results have allowed us to show the differential role of these abilities at different stages of learning more complex tasks. These studies have as an additional goal the specification of abilities predictive of advanced levels of learning.

One of our early studies was confined to the analyses of intertrial correlations of two similar tasks practiced in different orders (Fleishman, 1953a); but subsequent studies have always included "reference measures," external to the practice task. In a typical study, 200-300 subjects received a battery of reference tests known to sample certain abilities and then received practice on a criterion practice task. Through the use of factor analysis techniques of the correlation patterns obtained, we could examine *the loading* of successive trial scores on the criterion task on the abilities defined by the reference tasks.

In general, these studies, with a great variety of practice tasks, show that, (a) as practice continues, changes occur in the particular combinations of abilities contributing to performance, (b) these changes are progressive and systematic and eventually become stabilized, (c) the contribution of "nonmotor" abilities (e.g., verbal, spatial), which may play a role early in learning, decreases systematically with practice, relative to "motor abilities," and (d) there is also an increase in a factor specific to the task itself.

Figure 26 illustrates a typical result obtained using a visual-discrimination reaction task. See also Figure 27 which shows that certain abilities discriminate individuals high and low in proficiency early in learning a complex task, but not later in learning, while other abilities discriminate mainly at advanced levels of learning.

The repeated findings of an increase in specificity of the tasks learned indicates that performance in perceptual-motor tasks becomes increasingly a function of habits and skills acquired in the task itself. But pre-task abilities play a role, too, and their interactions with learning phenomena are important sources of variance to be studied. Furthermore, it appears desirable to better define the variance now termed specific to individual tasks. I am optimistic that some of this variance is not really "specific"; rather, we may need to be more ingenious at teasing it out.

Much of our later work has been concerned with the pursuit of this variance now defined as specific to late stages of learning tasks. Hypotheses we have explored are that, (a) late stage measures of different tasks have abilities in common not found in early stages of the same tasks (Fleishman, 1957a), (b) the ability to *integrate* component abilities represents a separate individual difference variable not found in early stage learning, (c) kinesthetic ability factors play an increasing role in psychomotor learning relative to spatial-visual abilities. Confirmation of hypothesis (c) was found in a recent study (Fleishman & Rich, 1963). In this study, we first had to develop a measure of "kinesthetic sensitivity" on which subjects differ reliably. Performance on this measure was a good indicator of late learning in a two-hand coordination task, but not of early learning.

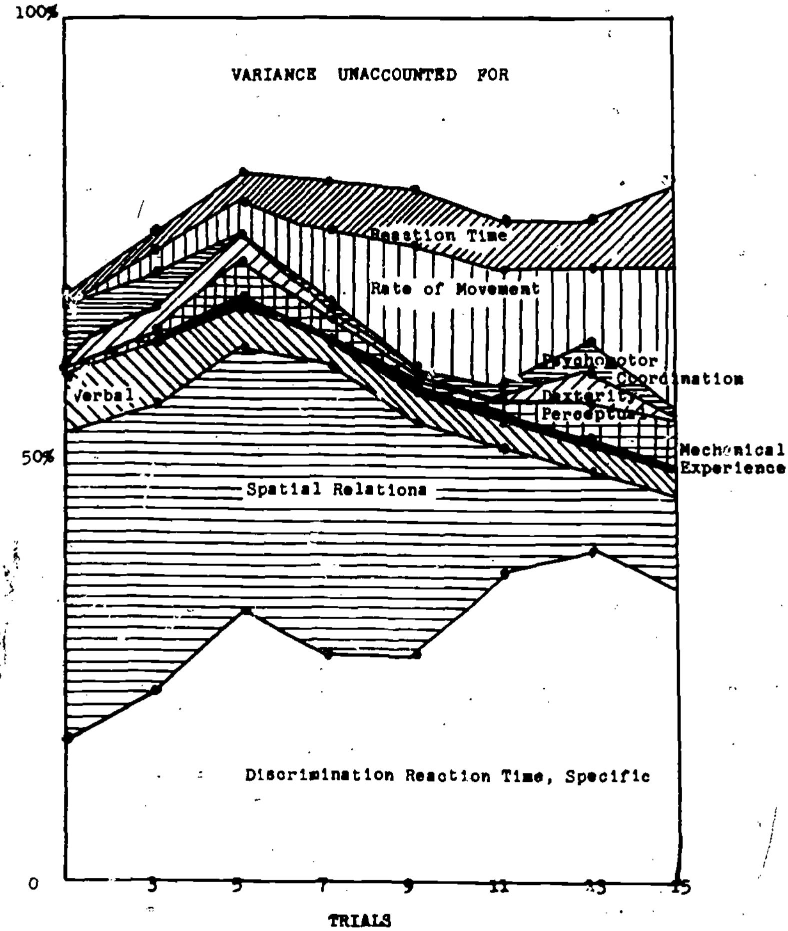

Figure 26. Percentage of variance represented by loadings on each ability factor at different stages of practice on the Discrimination Reaction Time task (percentage of variance is represented by the size of the shaded areas for each factor). (From Fleishman and Hempel, 1955)

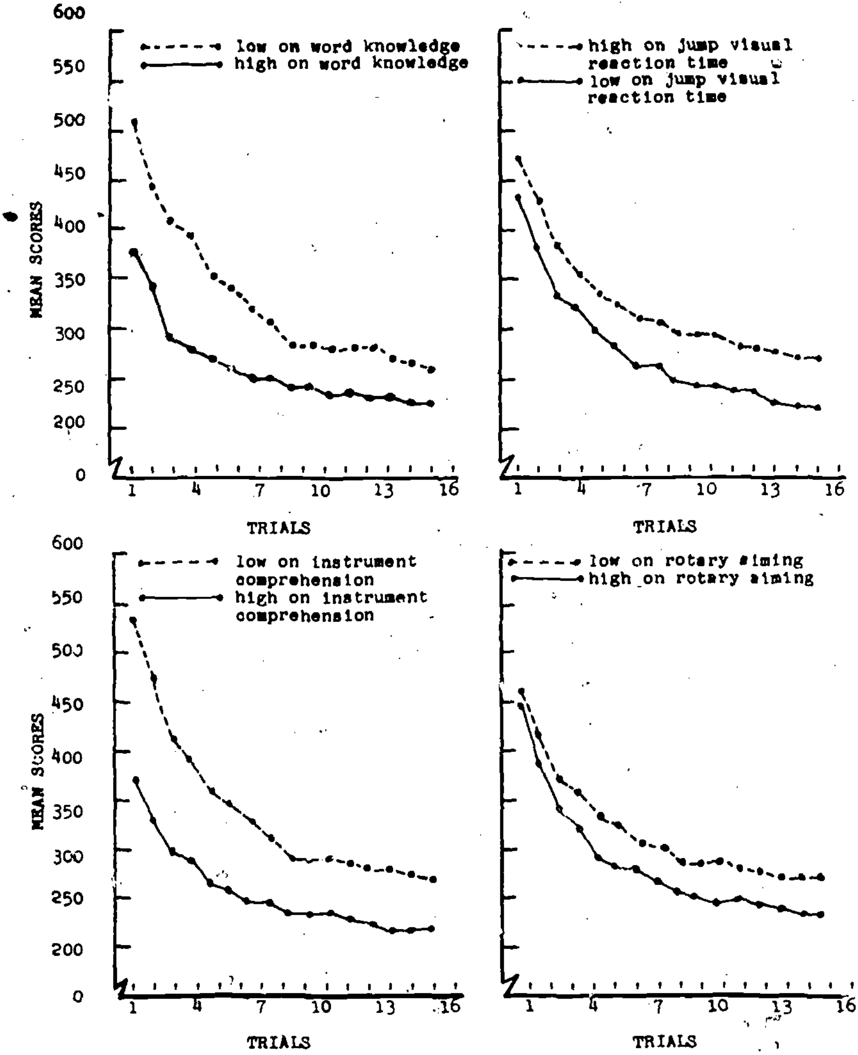

Figure 27. Comparison of learning curves on a Discrimination Reaction Time Task for groups stratified on different test variables. (From Fleishman and Hempel, 1955)

Use of the paradigm in training settings. Lately our findings and methods have been extended to more complex tasks studied over lengthy periods of time. In one study (Parker & Fleishman, 1960), we developed a simulation of an air intercept mission on which subjects learned a highly complex tracking task over a seven week period. The same 203 subjects received one of the most extensive batteries of perceptual-motor and cognitive tests ever assembled. The design allowed for the identification of 15 ability factors and the specification of their contribution to tracking performance at different stages of learning over this lengthy learning period.

In a later study (Parker & Fleishman, 1961), we attempted to make sure of our analytical information about ability requirements of this task, in designing a skill training program. In terms of our integrated error measure of performance during the last three training sessions, the experimental group showed a 39% increase in proficiency over the second best training condition investigated.

We have also studied the relation of ability variables to learning in a real training environment (Fleishman and Fruchter, 1960). In this latter case, we were able to show the abilities underlying the acquisition of skill, at different stages of Morse code learning, in an Air Force radio telegraphy school. Specifically, early learning depended on two auditory-perceptual abilities, whereas later learning was more a function of an ability named "speed of closure." This latter represented the ability to unify or organize an apparently disparate field into meaningful units. This study extends our findings on learning and individual differences to perceptual learning.

Individual differences and component-total task relationships. A recent study (Fleishman, 1965) investigated the relations between individual differences in performance on task components and subsequent performance on a total task. Two hundred and four subjects practiced the components of a complex multidimensional compensatory pursuit task singly and in combination. These components involved discrete display-control relationships. The total task, which was practiced last, required an integration of these components; that is, the subjects must operate the multiple controls in order to minimize error indications on all displays simultaneously. The problems investigated were, (a) the extent to which performance on task components, individually practiced, is predictive of subsequent total task performance; (b) the extent to which practice on combinations of components is predictive of total task performance; (c) the interrelationships among component performances; and (d) the relative contribution of various component performances to total and subtask performances. The analysis provides some tentative principles of part-whole task relationships relevant to the understanding of skilled performance.

Prediction of retention. I would not like to leave the topic of individual differences and skill learning without mentioning our studies on retention (Fleishman & Parker, 1962). Very little is known about individual differences in retention. We were able to give people extended (seven weeks) practice on a highly complex perceptual-motor skill and obtain matched groups of subjects back after periods of no practice for one four, nine, fourteen, and twenty-four months. Thus, we varied retention intervals, as well as type of initial guidance and level of original learning. The main points of interest here are that there was virtually no loss in skill regardless of the length of the retention interval, and that the most powerful variable operating was individual differences in the level of original learning. The prediction of retention from original learning was independent of the length of the retention interval. Thus, for all intervals, even up to two years, individual differences at the end of learning correlated in the .80's and .90's with subsequent performance after periods of no practice. Our design also allowed us to say that this prediction was not accounted for by the subject's pre-task abilities, but rather was explainable in terms of individual differences among subjects in the specific habits acquired in practicing the original task.

Individual Differences and Other Motor Learning Phenomena

A variety of other learning phenomena have been studied in relation to motor skill (see e.g., Bilodeau, 1966). These include transfer of training, habit interference, reminiscence, performance during massed versus distributed practice, etc. Little study has been made of abilities and other individual differences which predict performance under such conditions. A recent study has provided encouragement that a subject's previously developed abilities can help us make such predictions (Fleishman & Ellison, 1969). Subjects were given practice on a complex perceptual-motor task and later the display control relationships on the task were changed. Subjects were later shifted back to the original task. During initial learning subjects performed on massed as well as distributed trials. The same subjects received a series of motor, spatial ability and personality measures.

The study showed certain ability measures predicted which subjects would show the most transfer or interference at the shift points, but there was no "general susceptibility to interference" trait identified. Personality tests of "rigidity-flexibility," anxiety, etc., did not predict habit interference effects. Performance during massed practice was just as predictable from ability measures as performance during distributed practice. A major finding was the sharp *decrease* in prediction by ability tests of the trial following the massed practice (the reminiscence trial). There was also an increase in the predictions by the personality tests during this trial. Thus individual differences in recovery from "fatigue like" states (occasioned by massed practice) would seem to depend on different abilities than do other learning phenomena.

Concluding Remarks

Before closing, we may mention that little systematic work has been done in school settings with regard to motor skills development, prediction and evaluation. There are several additional issues here. One is the problem of using indices of motor abilities as diagnostic areas in predicting subsequent academic achievement and adjustments. Some educators feel this is a significant area, but the demonstration still needs to be made.

Another general issue is that of developing motor and other non-cognitive abilities and skills by some systematic educational program in the schools. It is probably safe to say that our educational system, while providing certain specific skills (e.g., spelling), is also aimed at developing certain general abilities capable of transfer to a variety of substantive areas and skills. (Elsewhere, I have elaborated the distinction between abilities and skills, e.g., Fleishman, 1967.) The general abilities which tend to be developed are cognitive abilities, e.g., verbal, numerical, conceptual abilities. Relatively little is done in the way of systematic, sequenced curriculum development to develop abilities such as spatial-visualization, manual dexterity, or perceptual-speed. Many of these abilities are more likely to be critical to non-academic fields or to areas of vocational or special education. Yet, early in a child's schooling it is impossible to know if the development of such abilities will eventually be relevant to his subsequent occupational choice.

Often overlooked is the relevance of such non-cognitive abilities to highly complex academic professions. For example, many potential engineers are lost, or make slower progress, not for lack of conceptual or mathematical abilities, but because of poor spatial orientation; many students have difficulties in dental school because of poor manual dexterity or spatial-visualization. The point is that there is ample justification and need for systematic programs for developing non-cognitive skills, in their own right, within the framework of our school system. With respect to the area of motor skill, this underlines the need for basic assessment techniques to assess base-line levels and progress through whatever program is developed.

The same need applies to the problems utilizing motor ability assessment techniques in predicting subsequent achievements in early school grades. There are many hypotheses, but little hard data, on the relevance of motor difficulties to later problems in learning academic skills. Many techniques used by teachers are too subjective (for example, noting how a pupil holds his pencil) and subject to error. It would be difficult to have much confidence in such assessments. It is really not known if a deviant 4th grade child can be identified at the kindergarten level through some specific motor ability deficit. What is needed is a set of standardized motor skill tests, with sufficient normative data and predictive validity.

What do we know at present and what can we do? We know from a vast body of research, much of which has been cited above, that there is no such unitary thing as motor skill. Although most of the research has been with older children and young adults, it is very clear that there are several dimensions of motor abilities which need to be assessed. Measures of each of these dimensions (or factors) correlate low with each other and have different predictive implications and lead to different programs of training for their development. A conclusion drawn from a measure of manual dexterity, for example, may be quite different from one drawn from a test of multi-limb coordination.

The specification of the motor ability factors identified, provides the idealized coverage for a comprehensive battery of motor ability tests. If it is not feasible to cover each factor, they at least provide a basis for selection. The factors specified also provide the basis for material development to specifically try to improve particular motor abilities.

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APPENDIX A
"THE BASIC FITNESS TESTS"*

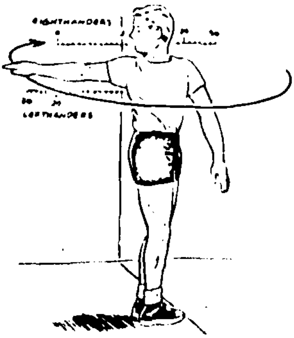

Figure 1. Extent Flexibility

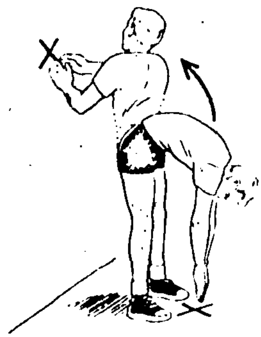

Figure 2. Dynamic Flexibility

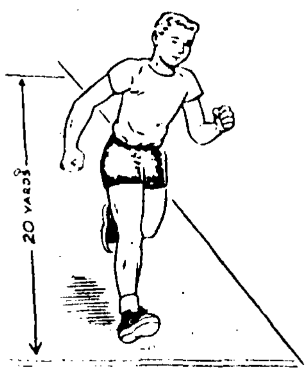

Figure 3A. Explosive Strength: Shuttle Run

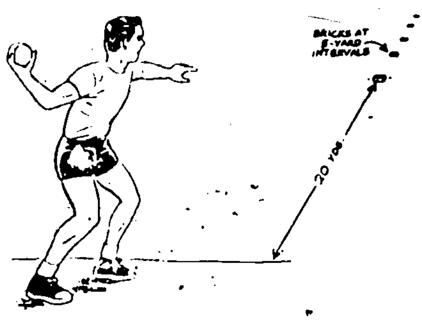

Figure 3B. Explosive Strength: Softball Throw

*(Fleishman, E.A., 1964 a, b)

PHYSICAL PROFICIENCY ABILITIES

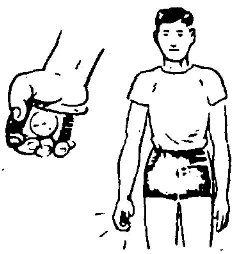

Figure 4. Static Strength: Hand Grip

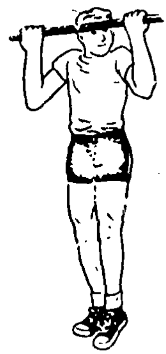

Figure 5. Dynamic Strength: Pull Ups

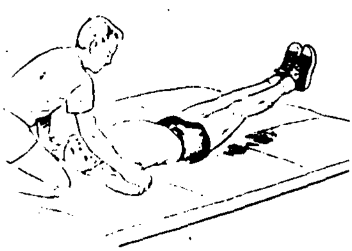

Figure 6. Trunk Strength: Leg Lifts

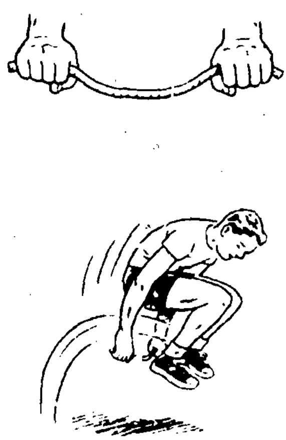

Figure 7. Gross Body Coordination: Cable Jump

PHYSICAL PROFICIENCY ABILITIES

Figure 8. Gross Body Equilibrium: Balance A

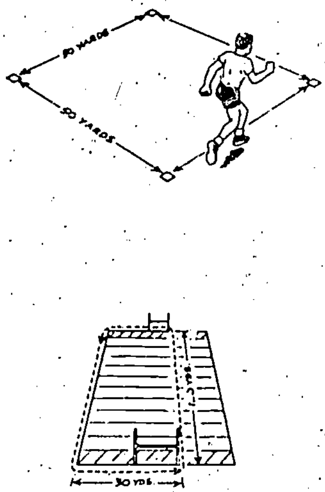

Figure 9. Stamina: 600 yard Run - Walk

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An Examination of Four Major Factors Impacting on Psychomotor Performance Effectiveness

Contents

An Examination of Four Major Factors Impacting on Psychomotor Performance Effectiveness

George D. Greer, Jr., James D. Hitt, Thomas E. Sitterley, and Edward B. Slebodnick
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Focus

The authors interpretation of their mandate in attempting to contribute to the conference is to concentrate on highly application-oriented data and information regarding factors impacting on psychomotor performance. This orientation reflects the high pressure, day-to-day professional concern of the authors with applications through all or most of their professional careers. As human factors specialists in the military/industrial context, identifying and resolving problems associated with man-in-a-system to assure that the system will function properly has been our way of life and is the way we think.

With this brief orientation as to our frame of reference in selecting and presenting the views in this paper, we feel constrained to make three points.

First, we find it all but impossible to meaningfully delimit psychomotor performance in any but the broadest sense. To state the obvious, we see it as always involving some kind of motor performance. But performance cannot occur except by an individual, with his idiosyncrasies and physical-mental state, in the presence of some stimulus/environmental situation. Thus, we will treat psychomotor performance as very broadly defined.

A second point regarding preparation of this paper is the fact that "psychomotor performance," even defined in its most limited sense, can still be construed to constitute the subject of a major portion of research conducted over the past 100 years. It is not our intention to re-review this vast array of material. Rather, we have elected to be highly selective, concentrating on data generated relatively recently, some of which may not have had wide circulation, but which is very much in need of integration if it is to add to the general body of useful knowledge on psychomotor performance. Occasionally, significant experimental methodological lessons have been learned, particularly regarding measurement criteria, time and subject motivation. These will be pointed out where they have been significant. Despite our attempts at being highly selective, like topsy, the paper just seemed to grow and grow.

A final point, i the generally "global" approach taker necessary for much of our real-world problem-solving research. Me ogically, this may be the most significant distinguishing factor between how the truly applied and the truly basic researcher thinks and goes about his business. In industry, we generally sacrifice understanding of the impact that a precise, specific variable has on a particular performance element, in the interest of determining the impact of the totality of the anticipated "stimulus-response-environment-individual-difference" context on system effectiveness.

There are exceptions to this, of course, where we may become very much concerned with the effect of a highly circumscribed display parameter (i.e., spot size, color, or movement) or a severely limited element of an individual perceptual or response capability (i.e., peripheral visual acuity). The latter, however, is more the exception than the rule in a successful human factors laboratory.

The basic researcher, on the other hand, sacrifices knowledge about the interactions of the specific stimulus and/or response to which he is directing his attention, with the multitude of other simultaneously occurring real world variables, both stimulus and response. He does this on the assumption, presumably, that the ultimate end-product will be much more fully understood, and be more generalizable, in the form of first and second order "laws." The laws, then, would allow both inductive and deductive generalization with the confidence that comes with understanding the internal workings of a complex process. It is obvious that both approaches, and various mixtures between the extremes of each, are necessary in the advancement of man's systematic knowledge as to the prediction, control, and modification of human psychomotor performance.

The paper, after this introduction, is divided into five sections. The first four each on a different set of factors influencing psychomotor behavior. The factors are Environmental Stressors, Time/Work (fatigue), Toxic and Drug Effects and Task Loading. These factors are related, in some instances highly so, in terms of the similarity of their impact on performance. Thus, in a fifth section an attempt is made to identify common elements of the effects of the four sets of variables on performance, emphasizing implications for acquisition of psychomotor skills.

Section A. Environmental Stressors

1. *Definition and Scope*

An environmental stressor may be defined as any condition of man's external environment which in some way affects his physiological safety and/or ability to perform sensory or motor functions. In the operation and maintenance of aerospace systems, man is called upon to perform a wide range of tasks under an array of environmental conditions. The environments under consideration will be limited to the conditions of temperature, noise, altitude, and vibration, which are the most common stressors affecting man's psychomotor performance in the aerospace systems environment. The general task categories to be summarized will include vigilance, reaction time, simple motor tasks (switch operation), complex motor tasks (tracking), and to some extent, mental processes and concentration.

Extensive reviews of what has been done in the area of physiological and performance effects of the environment (Roth, ed., 1968), point up the fact that available scientific data are very sketchy and unsystematic with regard to the environments, the levels of the environments, and the nature of the tasks investigated. Experimental studies are relatively few and no general behavioral or psycho-physical theory has been developed to provide a systematic description of the effects of environment on human performance (Teichner and Olson, 1969).

In this section, we will pull together a few selected examples of data and commentary to highlight the complexity, methodology, and implications of the existing research.

2. *Stressors and Effects*

The effects of each of the four environmental stressors will be summarized individually before discussion of the psychomotor effects produced by combination of the stressors.

(a) Temperature

When we think of temperature, we often visualize a thermometer. A thermometer is used to provide a measure of temperature which will support a decision to wear shorts or a sweater when leaving the house, but there are times when we are fooled by this relatively imprecise measure. The wind may be blowing or the humidity may be high, and we find that our subjective feeling of discomfort belies the thermometer.

"Temperature" must be redefined, at a minimum, in terms of a combination of heat, humidity, and air velocity. The amount of heat present in external environment is commonly described by two measures: *dry-*

bulb or ambient (air) temperature. and *wet-bulb* temperature. Combined with air velocity, these two measures of temperature are the most commonly reported means of specifying the independent variable: temperature stress.

A number of integrated measures of heat and cold stress have been developed to describe comfort and tolerance limits of exposure. The simplest of these measures is the "Oxford" or wet/dry (W/D) Index, which is nothing more than a weighting of wet-bulb (85%) and dry-bulb (15%) temperatures. A generally more useful measure is the Effective-Temperature (ET) Index. This index integrates the effects of temperature, humidity, and air velocity and is based upon subjective reports of heat, comfort, and cold. Combinations of temperature, humidity, and air velocity which produce the same subjective feeling are given the same ET. Another index which provides a descriptive quantity against which cold stress may be evaluated is the Windchill Index. Windchill has come into use as a single-valued index of the severity of the combination of air velocity (wind) and temperature (Fig. 5-1A). However, based upon WW II field measurement on the rate of cooling a container of water, the Windchill Index does not account for physiological adaptation and should not be used as a rigorous measure. There are other indices of temperature stress such as the Heat-Stress Index and the Operative Temperature Index. both of which are useful in environmental control system design. Unfortunately. there is no one standard index in general use that encompasses all the critical variables: thus, apparently valuable data is still being reported without all of the elements of the independent variable defined.

In the non-compensable zones of thermal regulation, performance and tolerance have an inverse exponential relationship with exposure time. As a "rule of thumb," performance begins to deteriorate for any given condition at about 75 percent of the physiological tolerance limit. It is possible, however, to exceed these values for short periods of time through adaptation and habituation, or through motivation. A contradictory phenomenon is observed at temperature levels just below the upper limits; sometimes performance is impaired, sometimes there is no change. and sometimes significant facilitation is observed.

Perhaps this confusion may be resolved in part. by analyzing the types of tasks performed. Numerous studies investigating the effects of heat stress between 80° and 120° F (ET) have found either facilitory or no effects upon performance of the type normally associated with simple eye-hand coordination and manual dexterity (Duke et al. 1967). Those tasks involving simple motor reactions, requiring little mental encoding, decoding, or translation. can be expected to benefit from the alerting component of stress arousal. Tests where the psychomotor tasks is more complex (i.e., greater involvement of higher mental processes and attention), degradation has been observed (Reilly and Parker. 1968). From a number of studies it

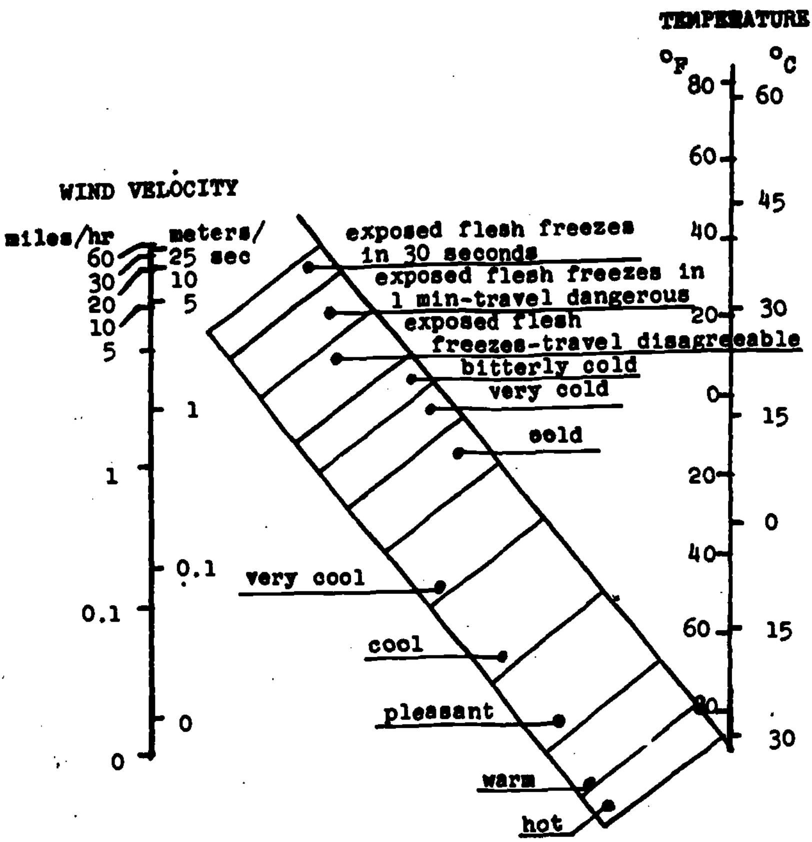


Figure 5-1A. In outdoor cold weather, the wind velocity has a profound, sometimes decisive, effect on the hazard to men who are exposed. The windchill concept dramatizes this well known fact by providing a means for quantitative comparison of various combinations of temperatures and wind speed. Note for example that -50°F with an air movement of 0.1 mph has the same windchill value, and therefore is predicted to produce the same sensation on exposed skin, as -15°F with a wind of only 1 mph or +14°F with a wind of 5 mph. (Windchill Nomogram, Bottomlay and Roth, 1968) might be concluded that under conditions of heat stress, simple psychomotor tasks show no difference or are facilitated, while more complex or cognitively oriented tasks are seen to suffer.

The relationship between psychomotor performance and subjective estimates of comfort as shown by Dean and McGlothlen (1965) provide another clue to the interaction between the simple and more complex or cognitive task effects. They found no effects on performance as a function of heat; however, subjective estimates of comfort and performance were found to be related and were significantly influenced by heat (Figure 5-2A). Subjectively, performance was judged to drop off sharply, the cognitive component was affected, even though this was not evidenced in the task performance data.

For multiple complex task performance involving a great deal of higher mental processing such as aircraft piloting, we find a striking lack of solid research data. One study (Blockly and Lyman, 1951), evaluating the effects of temperatures higher than those we initially looked at, provides some important findings. The task required trained pilots to fly a prescribed flight pattern in a simulated aircraft cockpit under high ambient temperature conditions until their tolerance limit was reached (ranging from a mean of 61 minutes at 160° to 21 minutes at 235°). The authors report

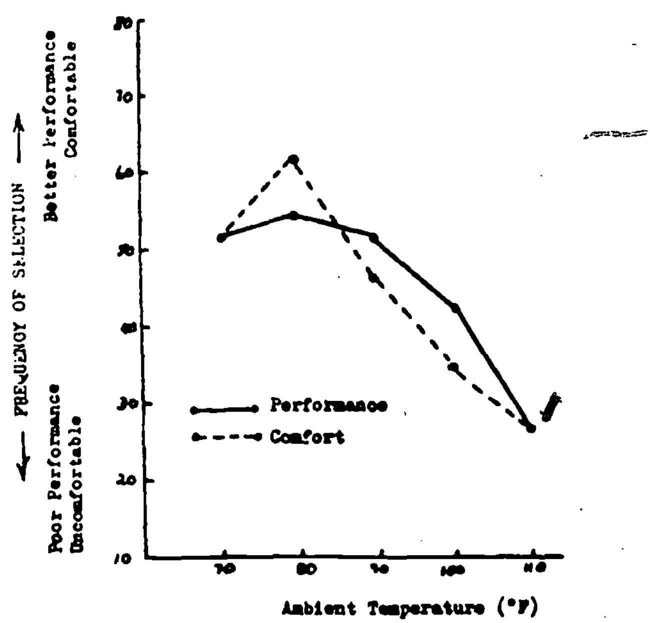


Figure 5-2A. The Effect of Heat Stress on Subjective Estimates of Performance and Comfort; Measured Performance Was Not Affected (Dean and Mcglothlen, 1965) that significant deterioration in performance simultaneously occurred with distress symptoms verbalized by the subjects. While all subjects displayed this deterioration, the pilots who were more competent at the control temperature 80° F had one-third the errors of the less competent pilots at the 200° F condition. This finding suggests that high skill levels can mitigate the influence of heat and stress. Subjects found themselves concentrating on one instrument at a time, so that by the time one flight function was adjusted to the correct value they would suddenly realize another had deviated from the desired reading. The ability to shift attention back and forth between sub-task elements was that which was impaired during the high temperature exposures. These results are comparable to effects of fatigue and high task loading.

The evidence that heat affects human performance is not without its inconsistencies; however, it is certainly reasonable to conclude that decrements become more pronounced as task complexity, exposure durations, and temperatures are increased. An important fact to note is that training appears to alleviate or reduce the onset of performance decrements to some extent; however, training is obviously not a panacea. The effects of prolonged quasi-compensable and rather short non-compensable heat will degrade the ability of an operator to attend to the elements of a multicomponent task. The operator will attempt to perform only those task components which he feels are most important, essentially forgetting about the remainder.

The reported effects of cold temperature environments on psychomotor performance are relatively free from inconsistency. The primary reason for this is that tactual sensitivity and manual dexterity are elemental in the performance of psychomotor tasks. The direct effects of cooling on the temperature of the skin and the viscosity of the fluids in the joints reduces manual dexterity and sensitivity of the skin to stimulation in a very orderly and progressive manner.

Tactual sensitivity is markedly affected by lowered skin temperature caused by the combined effects of reduced environmental temperatures and wind velocity. The ability of an individual to discriminate the separateness in space of two points or two straight edges placed on the finger, appears to approach infinity at skin temperatures slightly greater than freezing. Impairment has been found to begin at skin temperatures as high as 86° F for tactual sensitivity and 68° F for kinesthetic sensitivity. This minimum impairment becomes more serious around 43° F and marked decrement in sensitivity has been found at 30° F. A particularly critical factor in the maintenance of performance is that the individuals are rarely aware that the skin temperatures are so low and do not initiate preventative or remedial measures.

Reduced tactual sensitivity is generally associated with a reduction in manual dexterity. Investigations of manual dexterity have found progressive decrements as joint surface temperature drops below 43° F. Regardless of body temperatures, subjects with cold hands or fingers showed significant dexterity performance decrements, while those with warm hands showed no such decrement. There is some indication that in tasks where forearm muscle involvement is required, the temperature of the forearm can be critical in maintaining manual dexterity in the cold. Performance may also be somewhat impaired as a result of distraction caused by the discomfort of the cold, particularly under conditions where local cooling of the hand occurs and something more than light pressure is required to make the response.

It is reasonably safe to conclude that the limiting factor for psychomotor task performance in the cold is the temperature of the extremities. If performance is to be maintained or extended at extremely low temperatures, methods to protect the hands and fingers (or feet) must be provided. There are difficulties and penalties associated with this protection. It has been found that frequent warming of the hands and body can be a satisfactory remedy; but is a remedy which requires additional time away from the task and, therefore, may be neither practical nor economical for many tasks and emergencies.

(b) Noise

Noise is usually defined as any undesirable nonsymbolic meaningless, or meaningful sound. Undesirability of sound is based upon its capacity to reduce psychomotor performance, produce annoyance, discomfort, or injury.

The important parameters of sound (or noise), are frequency and waveform, amplitude, and duration. Waveform is often specified in terms of the various frequency components of the sound and may be referred to as periodic (a series of integrally related single frequency components) or aperiodic (discrete frequency components or a continuum of components distributed over a broad band). Amplitude is measured as the alternating sound pressure superimposed on the normal atmospheric pressure in dynes per square centimeter or the equivalent, the microbar. Because man can hear sounds over an extremely broad range of sound pressures, it is customary to deal logrithmically with the sound pressure level with a relative unit called a decibel (db).

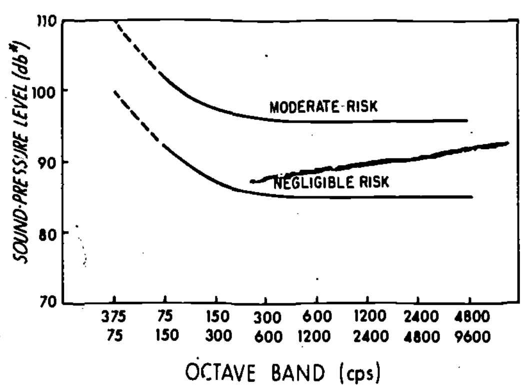
The prediction of noise tolerance is difficult because of individual differences, and its dependency on the duration and spectral composition of the sound. As would be expected, hearing losses resulting from noise exposures are greater with the higher noise (pressure) levels, longer exposure durations, and to some extent, with shorter bandwidths within which the energy is concentrated. Temporary hearing losses are produced rapidly and reach the maximum within about 7 minutes for exposure to pure tones.

The maximum loss from wide-band noise takes longer and depends upon whether or not it is steady-state or intermittent noise.

The extent of the annoyance or distraction produced by noise will depend upon its intensity and frequency, the subjective expectancy of its onset and feelings of its necessity, and the nature of the listener's activity and habituation. It is obvious to everyone that high levels of noise will disrupt auditory monitoring and communication performance. Noise mixed with a signal tends to raise the threshold for hearing the signal. This effect is called masking and the effect is greatest when the signal and noise are of similar frequencies.

Intermittent noise tends to have greater disruptive effects than the more rapidly habituated steady-state noise. Based upon reported data and some postulation, Teichner and Olson (1969) generated a series of curves (Figure 5-3A) representing attentional loss and recovery associated with expected and unexpected, steady-state and fluctuating noise. They assumed that the noise has no effect other than that of disruption. If the effect of noise is distracting, it should affect more complex tasks which require either a division of attention across several elements or the processing of signals at high rates. Accordingly, the greater the number of displays, or the complexity of a display, the greater is the likelihood that noise will interfere in task performance.

There is little evidence which indicates that noise environments, below destructive levels, have significant deleterious effects on non-auditory performance tasks beyond that of distraction or annoyance (Roth and Chambers, 1968; Morgan, et al, 1963). However, extremely high levels of noise can interfere with the accuracy of precision manual-dexterity tasks through noise induced vibration of body parts.



In general, we may conclude that noise will have its greatest effects on complex psychomotor performance tasks. Tasks which produce incoming signals at relatively high rates, or require attending to a number of stimulus elements or displays, will be most seriously affected. While it may be expected that the disruption of attention can result in focusing on only the more critical task elements, even those tasks which are complex or have a high information load will be affected. These conclusions have particular importance when viewed in a total task environment. We can expect noise effects to amplify in the presence of other factors which either reduce or place heavy demands on concentration and attention. Such factors as fatigue and task overload are prime targets for amplification of performance degrading noise effects.

There is some evidence which indicates that the effects of noise on performance are not all bad. Roth and Chambers (1968) indicate that noise and variations in noise patterns may have possible uses as positive psychological stimuli in the alleviation of isolation and monotony. In other cases, performance facilitation has been reported. The arousal effect of noise has been postulated as the mechanism to account for this facilitation. A recent study of target detection (Warner, 1969) showed that while target detection time was not affected by noise levels, the number of detection errors decreased significantly as the intensity of the noise increased from an unspecified control level to 90 db and 100 db. It could be postulated that the more intense noise was more arousing, and that this increased arousal facilitated performance as measured by the reduced error.

(c) Altitude

The psychomotor effects of altitude are due to the reduced partial pressure of oxygen, which is well known as one of the most critical requirements for human survival. The magnitude of these effects depends upon the extent and duration of the reduction in oxygen supply. There appears to be no evidence that high altitude without a corresponding oxygen deficiency (hypoxia), as measured by arterial saturation, will lead to performance decremen

The air we b athe contains approximately 20.95 percent oxygen. If we assume that the atmospheric pressure of dry air at sea level is 760 mmHg, the partial pressure of oxygen is 159 mmHg. At 10,000 ft., the atmospheric pressure of dry air drops to 522 mmHg and the partial pressure of oxygen takes a corresponding drop to 109 mmHg. The partial pressure of oxygen in the lungs (alveolar) and blood (arterial) is related to the atmospheric oxygen partial pressure in a somewhat complex fashion. Although oxygen partial pressure decreased linearly as a straight line with increasing altitude, the ability of the blood to hold oxygen goes down a slight slope for a short period (to 12 or 14 thousand fe t altitude) and then drops over a precipice.

The most sensitive indicator of hypoxia is the loss of visual functions. The effects of hypoxia may occur at 4,000 ft. in the form of diminished night vision and if one is at 8,000 or 9,000 ft. without supplemental oxygen, allowance should be made in those situations demanding good night vision or a high margin of safety. At 10,000 ft., the effects of hypoxia are definite, but generally unrecognized by the individual. Tasks of complex coordination and manipulation, such as handwriting begin to deteriorate in quality. McFarland (1968) admonishes that this is the maximum altitude at which an individual should consider his judgement to be sound and his performance acceptable.

At approximately 14,000 ft., McFarland considers an individual to be "appreciably handicapped." There is a dimming of vision and narrowing of the field of view, tremor of the hands, and impairment of thought and memory and, therefore, errors in judgement and performance. Disorientation, belligerence, or euphoric behavior and complete lack of rational judgement are observed at 16,000 ft. Less complex tasks such as pursuit and compensatory tracking and reaction time begin to deteriorate above this altitude. The average individual is considerably handicapped, dangerous as a pilot, and unable to perform reliably in other operational situations. At 18,000 ft. and above, the individual is seriously handicapped and is on the verge of collapse.

The duration of hypoxic exposure necessary to elicit the mentioned symptoms is very short, usually considered in terms of minutes of exposure. The critical duration may be exceeded to some extent by individuals who have unusual tolerance or resistance to hypoxia. Tasks for which the operator is highly trained or that require little effort or emotional response permit similarly longer periods of useful operation (Morgan, et al, 1963). However, "individuals who smoke should consider themselves 4,000 to 5,000 feet altitude above the non-smoker because of carbon monoxide levels in their blood and impaired diffusion of oxygen in their lung alveoli" (McFarland, 1968, pg. 7).

Perhaps the effect that is most dangerous to health and safety as well as acceptable task performance is the insidious onset of hypoxia. Experimental subjects are not aware of the impairment of their sensory, judgemental, and motor performance and are therefore unable to compensate for the decrements by exerting a greater effort. Individuals with operational experience at high altitudes must rely on their training and knowledge of altitude conditions in order to take action to preserve performance levels.

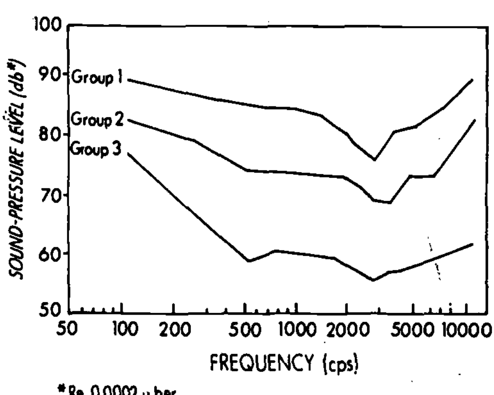
(d) Vibration

Vibration may well be one of the most common environmental stressors to which man is exposed. Every time he rides in a car, bus, truck, ship or airplane he is exposed to vibrations of varying degree, sometimes mild, sometimes annoying, and sometimes painful. Perhaps less obviously, vibration is a problem in work settings as well, such as using hand tools operating machinery, or working on production lines. Of interest to us are the effects of whole-body vibrational forces which displace bodily tissue beyond the threshold of perception and those which produce decrements in performance and feelings of annoyance and fatigue. In general these fall within the category of relatively high amplitude, low frequency vibratory forces of the type generated by machines or vehicles (Figure 5-4A).

The major parameters of vibration which are relevant to human vibration research are frequency, displacement, acceleration, and jolt.

Frequency is normally specified in cycles per second (cps) or Hertz (Hz) just as with noise. Displacement is defined as the maximum half-wave (single amplitude) or full-wave (double amplitude) displacement of the vibrating body. Acceleration is the second time derivative of displacement (inches/second or cm/second) and is expressed as maximum or peak "g". For random vibration it is customary to express acceleration as root mean square (r.m.s.) acceleration. Jolt is the rate of onset of linear impact and, as the third derivative of displacement, is expressed in inches/second^3. While infrequently reported in human vibration research, jolt is a significant factor in the evaluation of human tolerance to very low frequency vibrations such as the 0.5 Hz vibration of impact. As with all the other stressors, the duration of vibration is important in establishing its effects.

Vibration frequency differentially affects the various portions of the



human body. These differences are caused by impedances of the body and its parts and organs which damp vibration over certain frequency and displacement ranges. Likewise, for certain other frequencies and displacements, there are resonances which amplify the vibration within various portions of the body. The smaller the mass of the body part, the higher is the resonant frequency.

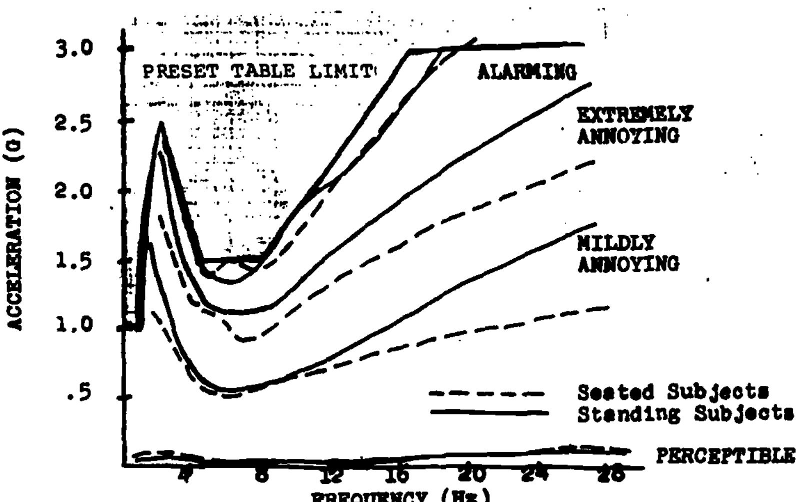
In addition to the biomechanical view of bodily response to vibration, subjective reaction studies have provided data relative to transient sensations which accompany whole-body vibration. Extensive catalogs of the bodily sensations to longitudinal vibration have been developed across the frequency range of 1 to 30 Hz for both seated (Parks and Snyder, 1961, and Chaney, 1964) and standing (Chaney, 1965) subjects (Figure 5-5A). The reports obtained from subjects have emphasized sensations of a disturbing or even painful character, involving itching, flapping or shaking of skin or appendages, mild pain, pressure and perceived tightness, as well as functional hinderances such as swallowing difficulty and blurring of vision. Beaupeurt et al (1969) have summarized the effects of vibration on the different bodily areas as a function of frequency for seated (Figure 5-6A) and standing (Figure 5-7A) subjects. In general, low frequency vibration (1 to 14 Hz) has the greatest subjective impact on the trunk and internal organs, while vibrations in the 15 to 27 Hz range are more disturbing to the head.

Vibration-tolerance criteria for vibration exposure is somewhat difficult to specify. The limits developed by various investigators agree only within limits since the evaluation criteria, positioning, and body support have marked effect on subjective estimates of comfort. The present table limit and the linearized step curve in Figure 5-8A provide a good indication of tolerance limits to sinusoidal vibration.

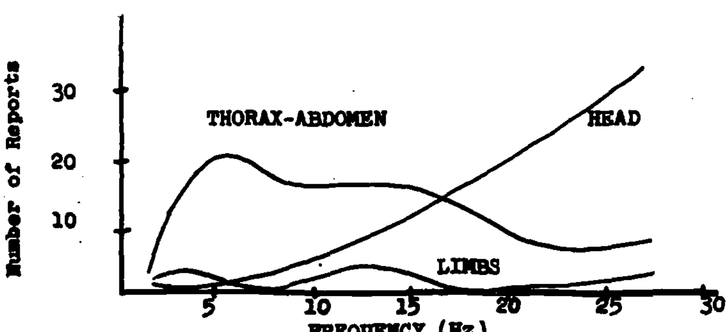
The psychomotor effects of vibration are generally considered to be caused by direct mechanical interference, and in some cases as indirect effects resulting from fatigue. The mechanical interference characteristics would lead us to expect that vibration will primarily affect the motor component of task performance, with some effects on the visual component for tasks demanding relatively precise visual fixation.

Vibration of either the viewer or the object can blur vision over certain frequency and acceleration ranges and is usually attributed to movement of the retinal image at a speed too great to be followed by the eye (Tears and Parks, 1963). There is no clear-cut evidence that the mechanical decrement in acuity is either purely frequency dependent or displacement dependent, however, the ability of the human eye to follow sinusoidal relative movement of a target begins to break down at 1 to 2 Hz.

Primarily visual tasks which do not require acuity or the ability to fixate are normally unaffected by vibration while secondary visual tasks are affected. This lack of effect on the primary task is evident in two studies of



a. Subjective Reaction Curves - Seated and Standing Subjects



b. Relationship Between Body Areas Affected by Vibration When Standing

Subjective Reactions and Body Areas Affected by Vibration in Seated and Standing Subjects. (Chaney, 1964, 1965)

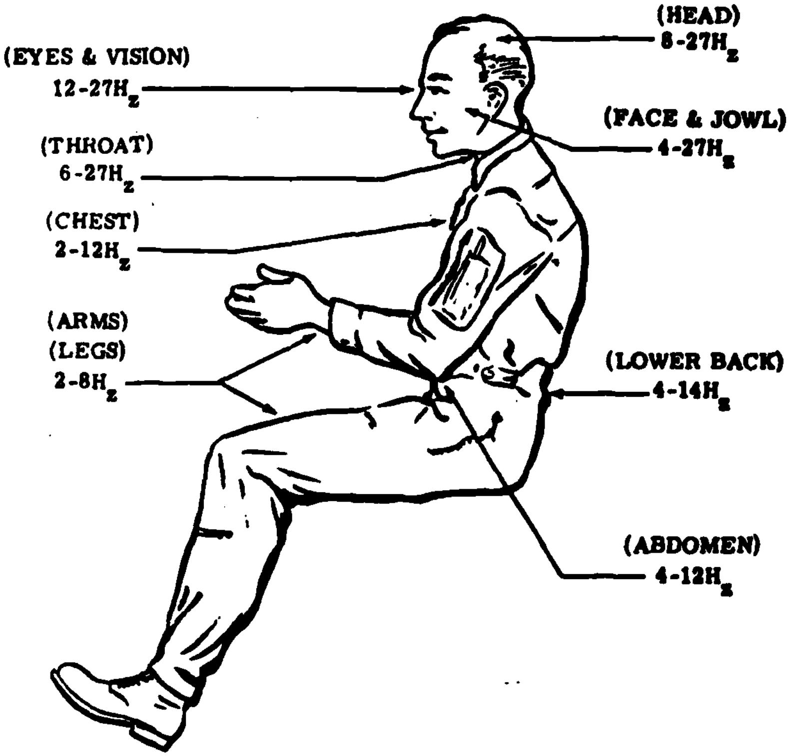


Figure 5-6A. Frequency Range for Concentrations of Disturbing Sensations for Whole-Body Vibration of Seated Subjects (Beaupeurt, 1969)

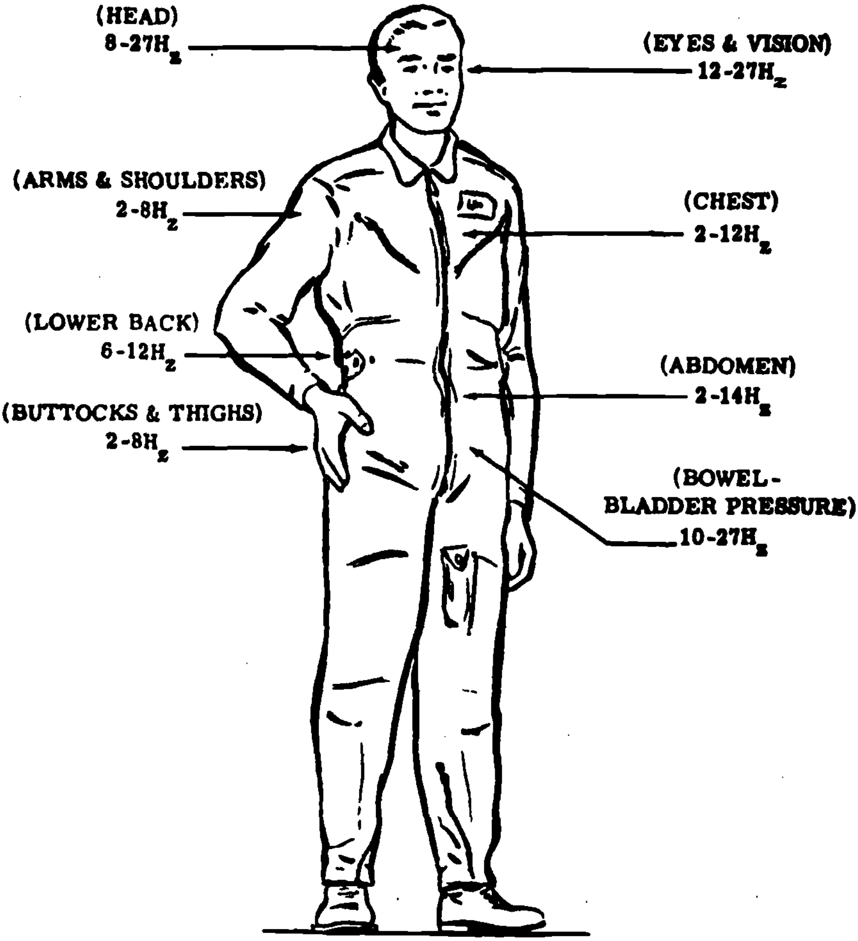


Figure 5-7A. Frequency Range for Concentrations of Disturbing Sensations for Whole-Body Vibration of Standing Subjects (Beaupeurt, 1969)

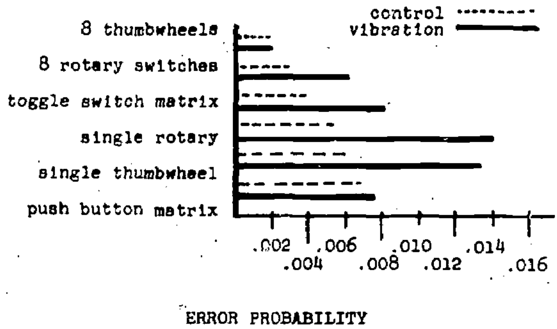


Figure 5-8A. The Effect of Random Whole-Body Vibration (0.2 to 0.8 RMSg) on the Accuracy of Inserting 8-Digit Numbers for Various Controls (Dean et al, 1969).

warning light monitoring tasks embedded in a group of simultaneously performed tasks (Holland, 1967 and Shoenberger, 1967).

Two major results were obtained: first, the significant decrements that occurred were at the higher g levels; and second, the stress of vibration environments brought about a reduction in the range of visual cue utilization that was seen as a decrement in the most peripheral components of the tasks. Vibration can be viewed as producing an additional operative load much like the effect of task overloading.

In what may be a classical approach to studying the effects of random vibration on psychomotor performance, Dean et al, (1969) conducted three experiments to determine the effects of mechanical vibration on the operation of decimal input controls. The task required the subjects to view an eight digit register and input the numbers into a control system as rapidly and accurately as possible. There were six input panel configurations and four basic types of controls: push buttons, toggle switches, rotary switches, and thumbwheels. The vibration environment was a random, 2 to 30 Hz spectrum which ranged in intensity from 0.2 to 0.8 rmsg with a control condition. In the first experiment, insertion time and all error indexes showed significantly poorer performance under vibration (Figure 5-9A). After the subjects had learned the task and had become practiced in performing under vibration in the earlier experiment, they were able to maintain accuracy in the last study by taking longer time to perform the task. The outstanding feature of this study is that, with training, subjects are able to continue to perform in an integrated manner at all levels of vibration, even though the upper levels were sufficient to cause intense discom-

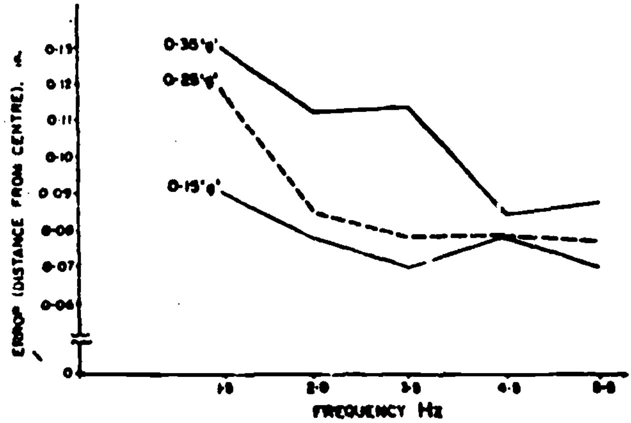


Figure 5-9A. Performance of a Compensatory Tracking Task as a Function of Frequency and Intensity of Transverse Whole-Body Vibration (Hornick, 1961)

As we look at more complex tasks such as compensatory tracking, we find that whole-body sinusoidal vibration at acceleration-amplitudes exceeding 0.1 g in the 1 to 30 Hz frequency range can produce a significant increase in errors (Roth and Chambers, 1968b).

Hornick et al (1961) have shown that transverse or lateral vibration, significantly lowers compensatory tracking performance. The frequency of 1.5 Hz was considered to be a particularly disturbing frequency of vibration. What appears critical is that the frequencies which produce the greatest resonance in the task-involved body part will produce decrements in psychomotor performance at relatively low g levels (Holland, 1967; Harris and Schoenberger, 1966) and we see the greatest decrement in performance when tracking in the same axis as the vibration (Morris, 1966; Holland, 1967).

The six hour duration of vibration exposure makes Holland's (1967) study unique in vibration research. By maintaining the test subjects in a continuous environment he approached more closely the conditions often found in the real world work setting. As might be expected, the duration of exposure had its effect on performance. Almost without exception, tracking error progressively increased throughout each test session. Considering its significant effects on performance, we can guess vibration will considerably amplify fatigue effects due to other causes. Similar to the results obtained by Dean, et al, (1969), a second result was that performance improved over test sessions. Holland indicates that the improved tracking performance across test sessions probably reflects an adjustment or adaptation to the vibration conditions. It appears appropriate to imply there are two learning situations: learning to perform the task and learning to perform the task under conditions of vibration.

We can conclude that the effects of vibration on measures of psychomotor performance have yielded varied results depending more on the nature of the tests than on the quality of the environmental stress. In general, those tests which call for maintained intensity, gross motor movement, or are primarily mental or cognitive in nature, reveal little or no decrement in performance during low frequency vibration. On the other hand, tasks which require precise muscular coordination or positioned control of limbs and extremities do show adverse effects. The quality of the vibration has a somewhat confusing influence on performance and is most probably related to the intensity of the vibration which affects the portion of the body most involved in performance of the task. While it is evident that vibrations encountered in many work settings will have detrimental effects on task performance, the effects may be partially alleviated through training procedures which expose the learner to the vibration conditions he is expected to encounter.

(e) Combined Environmental Stressors

Environmental stressors have been investigated for decades. A survey of the available literature, however, will reveal that almost all of the studies have investigated only a single environmental stressor. Only rarely have two or more stressors been investigated in combination. In attempting to understand and predict the effects of combinations of stressors which are characteristic of aerospace systems, this lack of investigation produces an emergent effect which is not equal to the simple sum of the single effects.

To extrapolate the effects of combined stressors from data obtained from studies of single stressors may be dangerous. Take for example the designer of a new space vehicle who is concerned about the combined effects of temperature, noise, and vibration. If he simply adds the single effects to predict the combined effect, and the effects are more than additive, the pilot may be unable to perform his tasks or injured. However, if the effects are less than additive, the vehicle will be over-designed and unnecessarily expensive. This non-additivity may be thought of as an interaction similar to that in which the properties of a combination of elements (water) may qualitatively differ from the properties of any or all of the elements (hydrogen and oxygen). We illustrate this interaction, within the context of environmental stressors, with a combination of stressors which produce a decrement in performance which can not be predicted from an addition of the individual effects. Of considerable interest has been the attempt to describe the nature of the combinations or interactions between stressors: are they additive, more than additive, less than additive, or produce no effect when combined.

Unfortunately, much of the work with combined stressors is as inconsistent as that with the single stressors. In 1964 Dean and McGlothlen (1965) attempted to determine the nature of the combination of the effects of heat (70° to 100° F) and noise (70 to 100 db) on human performance, comfort and physiology. They required their subjects to simultaneously perform tasks of tracking, radar monitoring, and meter monitoring. Outside of a single facilitory noise effect of reducing response time on the meter monitoring task, there were no differences between the stress and control conditions, much less any indication of an interactive effect of the combination.

A following study by Dean, McGlothlen, and Monroe (1964) was designed to evaluate the effects of repeated exposures to noise and vibration. Six helicopter pilots were tested under seven 40-minute exposures to realistic helicopter noise (up to 114 db) and vertical vibration (up to 0.41 RMSg) over a six-hour period. The tasks performed by the pilots were representative of cockpit tasks and included tracking, meter and warning light monitoring, and operation of switch action controls. No evidence of physiological or performance degredation was observed. In fact, the only performance change observed over the seven repeated exposures was significant improvement in tracking performance from the first of the last trials which may be interpreted as a learning to perform under conditions of environmental stress.

Two additional unreported studies by Dean (1964 and 1965) investigated the combined effects of heat (to 105° F), noise (to 124 db), and vibration (to 3.0 RMSg) on the ability to fly a realistically simulated three stage booster into orbit. Ten highly competent pilots and astronaut trainees flew the 9.5 minute boost flight using a complex of flight instruments and controls. The data in both studies failed to show any decrement in performance as compared to the control conditions.

We still cannot believe that stressors in combination produce no measurable effects on performance. The lack of decrements similar to those shown in single stressor studies cannot be attributed to lower task complexity, as these studies cover the range of tasks and complexity of any other study reported. The deciding factor may well lie within the realm of training and motivation. In all of these multiple stress studies conducted by Boeing, the subjects were highly skilled and experienced pilots who had been given additional training on the tasks (which were analogous to those of flying). Being professional pilots, they had an extremely high sense of motivation to do their job well and when their piloting skills were being measured, they showed a highly competitive spirit which seemed to lead them to apply their utmost capability to perform the tasks well, regardless of the conditions.

The significance of the benefits to be derived from high motivation and extensive training in the task can be inferred by comparison of results from a contrasting study by Dean and McGlothlen (1962) where the interactive effects of heat, noise and altitude were clearly shown. The subjects in this study had neither the prior task training and stress experience nor the motivating attitude associated with the subjects used in the studies described above.

The effects of eight environmental conditions were investigated which involved all possible combinations of the three single stress conditions (noise-temperature, noise-altitude, temperature-altitude, and noise-temperature-altitude) plus a non-stress control condition.

Nine measures of performance were obtained: four dealt with tracking, three with radar warning, and two with meter monitoring. All tasks contained both sensory and motor components and were characterized as either primary or secondary tasks. The data showed that both primary and secondary task performance was generally adversely affected by the single and combined stressors. The importance of this result rests with the fact that the subjects used were not highly trained, experienced, competitive, and motivated pilots which were used in the later studies described above.

The second major result of this study (Dean and McGlothlen, 1962) shows that where stressors do affect performance, combinations of environmental stressors may have different interactive effects on primary and secondary task performance (Figure 5-10A and 5-11A). The four combinations of environmental stressors affected the primary task of tracking in either an additive or less than additive manner while the effect of the stressor combinations on the secondary tasks was essentially opposite.

The less than additive effect on the primary task and the more than additive effect on the secondary tasks suggests that the subjects concentrated on the primary task at the cost of greatly decreasing their performance on the secondary tasks.

The narrowing of focus on only the key task elements, paralleling a similar effect on fatigue and task overload, may have important implications in the performance of even highly trained and motivated people. If the conditions of combined stressors, fatigue, and task overload are all present in an operational situation, it is probable that psychomotor performance will be degraded unless the utmost in motivation and skill level are present.

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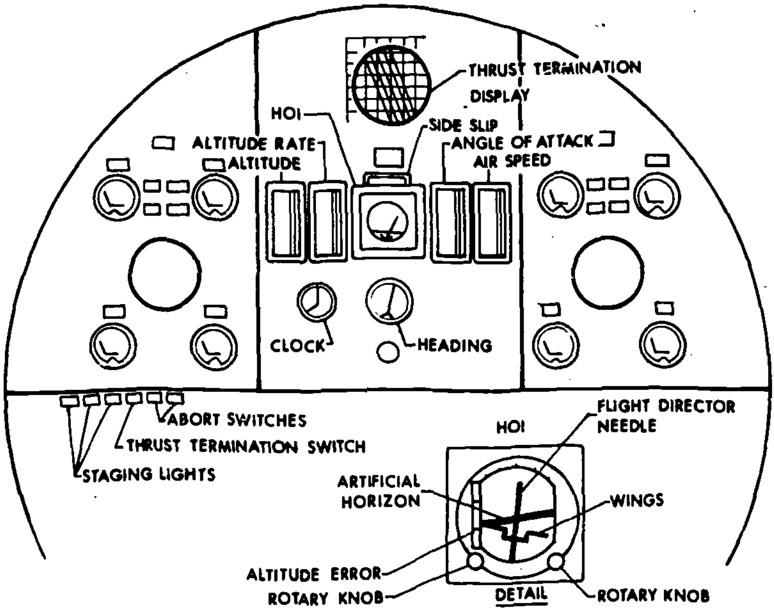


Figure 5-10A

	PRIMARY TASK	SECONDARY TASKS	PHYSIOLOGICAL VARIABLES
ALTITUDE, TEMPERATURE, AND NOISE	< •	> •	•
NOISE AND TEMPERATURE	< •	•	•
NOISE AND ALTITUDE	•	•	•
TEMPERATURE AND ALTITUDE	•	> •	•

• ADDITIVE EFFECT

< • LESS THAN ADDITIVE EFFECT

> • GREATER THAN ADDITIVE EFFECT

Figure 5-11A

Section B. Time and Work Effects

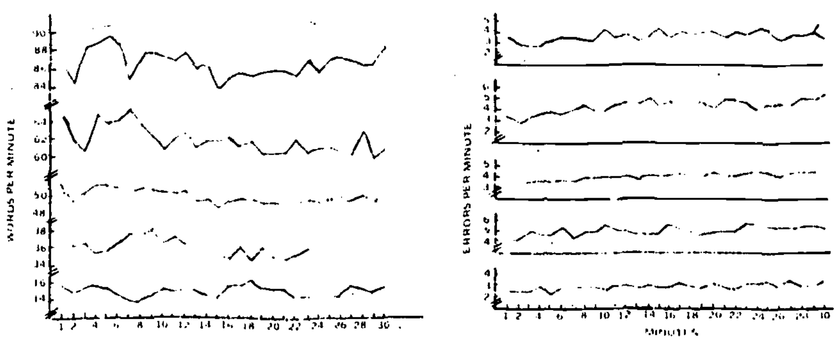
Processes and events occuring during passage of time may affect both rate and level of learning, as well as task performance output.

Time and work effects are interactive, since work effects show up in performance over time. The combined effects also interact with motivation and skill. Figure 5-1B shows typical performance decrements for several different types of tasks. These decrements may be controlled, reduced, or even eliminated by judicious task design, work-rest cycle programming, and motivation management.

Vigilance

The most dramatic time-effect is seen in vigilance performance decrement. Vigilance is a perceptual task; in effect, watch-keeping, monitoring, or inspection, where an observer is required to detect infrequent, random, low-intensity events. The simplest cure is to relieve the observer after 20 to 30 minutes but this is expensive, since it increases markedly the number of observers required to maintain constant vigilance. Perceptual performance

Figure 5 1B Depicts mean words and mean errors per minute in each of 30 consecutive min. of typing by skill level (N = 40 per level). (From West, 1969)



Mean words per minute in each of 30 consecutive min. of typing, by skill level (N 40 per level)

Mean errors per minute in each of 30 consecutive min. of typing by skill level (N 40 per level)

Fig. II. 5143

such as vigilance (watch-keeping), monitoring or inspecting, can be sustained by programming and highlighting stimulus material, so that critical stimuli are more apparent, and by training the observer to anticipate time and place of occurrence.

In a study of a simulated industrial inspection task, inspector efficiency was maintained best if the signal rate was high, i.e., there were many defective articles, so that they appear at short intervals. This suggests that "artificial defectives" might be programmed into the inspection task (Badalamente, 1969). Detection performance can also be improved by training the observer to know where or when to expect a signal. If the spatial and temporal characteristics of the detection task can be specified, the observer will have reference points, and can more efficiently focus his attention to detect critical signals.

Perceptual performance can be enhanced by specific stimulus-response training, with knowledge of results. Studies directed specifically to techniques for improving perceptual training seem to be rare, but Annett (1966) has described three methods of training in perceptual tasks which lead to improved performance, compared to simple practice. Annett's methods are: (a) cuing, by providing information about the forthcoming stimulus before its presentation: (b) providing knowledge of results after the response: and (c) reducing the difficulty of the material. All three were superior to a simple practice situation. Cuing was equal to or better than knowledge of results and training on easy material was least successful.

Observers may also be trained to detect in themselves the symptoms of "unalertness," and thus achieve a degree of motivational control. In an article on "Alertness Management in Industry," related to production rate, quality control, and operator safety (Moody and Duggar, 1966), alertness is defined as "the state of readiness to made responses appropriate to the requirements of the situation." The nature of alertness is said to involve not only vigilance but "set," fatigue, sleep and sensory deprivation, stress, and motivation. These authors "seriously doubt that people can be trained to be alert for long periods. They can, however, be trained to detect the signs of unalertness and take preventive measures." They cite, among truck drivers, reliable but highly individualistic symptoms which warn of falling asleep, and the idiosyncratic methods the drivers use to overcome sleepiness. Harry Jerison, a leading contributor to theoretical research on vigilance, has drawn some practical conclusions about alertness: ". . . the data of vigilance experiments suggest that regardless of when a signal occurs, if the observer is observing alertly he will not miss it. The . . . application . . . is . . . concentrate on techniques for maintaining alertness . . . design displays that make it more likely that the observer will be alert when a signal occurs."

Fatigue

Fatigue is variously defined and measured in terms of physiological states, subjective feelings. or measured performance decrement. Empirically established relationships among these various measures are at best tenuous and often contradictory.

Physiological measures of fatigue include oxygen consumption, energy expenditure, heart rate, and blood chemistry. Thus far, these measures have not been effectively related to performance decrement. (Pierson and Rich, 1967)

Fatigue effects, or sheer work decrement, depend in part upon physical fitness. but are also strongly influenced by worker skill and motivation. Though physiological fatigue products generally reduce the body capacity to perform work, sheer physical exertion does not necessarily lead to degraded task performance. In a study of the effect of a burst of violent exercise upon performance of skilled visual-motor tasks, one group of normally-fit men were compared to a group especially selected for outstanding physical fitness. Among normally-fit men, on a medium difficult task there was no performance decrement; while a very difficult task showed a significant decrement in tracking efficiency. For the "ultra-fit" group the effect was trivial and not significant (Hammerton and Tickner, 1968). Thus, jobs known to involve strenuous exertion should require selection for, or training in, physical fitness.

Subjective measures of fatigue range from reported "feelings of tiredness" after intensive exertion, to "feelings of boredom" after sedentary activity. These measures can sometimes be related to performance decrement, but the relationship is very likely confounded in that both performance and subjective feeling reports may be functions of the subject's motivation to perform the task. It has been empirically established that students or trainees are notoriously poor judges of their own fatigue, or the effects of fatigue on their own performance.

As with environmental stress, fatigue effects may be confounded with task complexity. Fatigue may have subtle effects only on secondary tasks. Workers may be trained to detect fatigue symptoms that presage performance decrement (Moody & Duggar, 1966), and trained or instructed to attend most carefully to critical tasks in a multi-task job.

Work-Rest Cycles

Human performance is susceptible to diurnal and circadian rhythms, as well as a variety of other neurophysiological and psychological periodicities. A recent discussion on man's normal neurophysiological and psychological rhythms, points to "some 50 such patterns of fluctuating functions . . .

which . . . influence . . . level of performance and ability to maintain performance." These performance variations are related to circadian rhythms, and a variety of other physiological, neurological, biochemical, cultural, occupational, and personal periodicities.

The most familiar circadian rhythm is the diurnal alternation of sleeping, waking, and eating. This cycle is of interest to SST developers, who recognize that flight crews will be called on to shuttle over longer distances, faster, and more frequently.

Obviously, adjustments are possible. Humans can adapt to working on altered cycles; and it is possible to control the environment to preclude obvious changes in diurnal cycles. The story may be apocryphal, but it is alleged that Russian pilots, after crossing seven time zones from Moscow to Havana, are restricted to a controlled layover hotel, where lighting, meals, and even clocks are maintained on Moscow time.

Trumbull (1966) points to cyclic variations in reaction-time, memory, various performance tasks, as well as a variety of internal states, and concludes "that mental and physical efficiency correlate with basic physiological rhythms." These rhythms range from neural activity in the reticular activating system in the brain stem, through refractory periods in a nerve cell, to time-of-day, and beyond, to lunar cycle periodicities. He suggests that we prepare "periodicity maps" with which to coordinate activity schedules. These periodicities are reliable, yet quite individual.

Moody and Duggar (1966), discuss individual differences in the times at which peak arousal may occur, and suggest, for highly critical task situations, that work be cycled to coincide with the individual's natural period of peak arousal or periodicity map.

Chiles, Allusi, and Adams (1968) report on cyclic variations in physiological states (pulse rate, skin temperature, axillary temperature, and skin resistance) and performance on psychomotor and cognitive tasks. Their studies, in support of long duration mission aircraft development, sought to establish manning requirements, work/rest schedules, and mission duration limits. Mission task performance and physiological states were both related to diurnal cycle as well as to work-load, work period duration, work/rest schedules, duty period duration, and mission duration. Their results are specific to the system situation, but they show generally that performance on a 4-on/4-off schedule was comparable to a normal eight-hour split-shift work day; and that the 4/4 schedule was better (in terms of performance) and less taxing (in terms of performance reserves) than a 4/2 schedule.

Circadian rhythmic peaks in both performance and psychophysiological functions tended to occur in parallel. This diurnal performance variability was brought under motivational control, however, by 6 highly motivated Air Force cadets who were instructed in diurnal effects and urged to work to prevent decrements (Chiles, *et al*, 1968).

Work/rest schedules in industrial situations involve shift structure, scheduling of rest pauses, and the nature of the rest pause. Shift schedules which are contrary to worker preference may produce morale problems rather than direct work performance decrement (Dirken, 1966).

An applied industrial study of the nature of a rest pause compared a passive pause to a gymnastic pause. The gymnastic pause resulted in improved hand steadiness, diminished general fatigue and eye fatigue, faster work, and greater muscular strength. So rest, *per se*, is not the ideal way to fill a coffee break (La Porte, 1966).

A common instructional work cycle is the conventional method of presenting short 1 to 3 minute practice and test sessions in early typing training. Typing performance measured over 30-minute practice sessions, however, produced both word-per-minute and error-per-minute scores which were surprisingly stable. Absolute decrements were trivial (West, 1969). Of further interest to typing instructors was the finding that it takes at least a 5-minute straight-copying typing test to achieve a reliable measure of typing error.

The studies in the area of work scheduling lead to the general conclusion that both training and job tasks can profitably be structured to take advantage of recurrent peaks in capability, though there are social and cultural limits to the practicality of such programming. U.S. airline pilots would not take kindly to a controlled layover hotel in Paris.

Summary Time and Work Effects

Processes and events occuring during passage of time may affect both rate and level of learning, as well as task performance output. Time and work effects are interactive, since work effects show up in performance over time. The combined effects also interact with motivation and skill.

Perceptual performance such as vigilance ("watch-keeping," monitoring, or inspecting) can be sustained by programming and highlighting stimulus material, so that critical stimuli are more apparent, and by training the observer to anticipate time and place of occurrence (Badalamente, 1969). Specific stimulus-response training, with knowledge of results, will enhance perceptual performance (Arnett, 1966). Observers may also be trained to detect in themselves the symptoms of "unalertness," and thus achieve a degree of motivational control (Moody & Daggar, 1966; Jerison, 1967).

Fatigue effects, or sheer work decrement, depend in part upon physical fitness, but are also strongly influenced by worker skill and motivation. As with environmental stress, fatigue may have subtle effects on secondary tasks; and subjective worker reports are not reliable performance measures. Jobs known to involve strenuous exertion should require selection for, or training in, physical fitness (Hammerton & Tickner, 1968). Workers may be trained also to detect fatigue symptoms that presage performance decrement (Moody & Duggar, 1966); and trained or instructed to attend most fully to critical tasks in a multi-task job.

Human performance is susceptible to diurnal and circadian rhythms, as well as some fifty other neurophysiological and psychological periodicities (Trumbull, 1966). With special motivation, subjects can minimize diurnal variations in performance (Chiles, 1968). Work scheduling may preclude both time and work decrements, if organized to take advantage of peak capability periods, and avoid known cyclic depressions (Trumbull, 1966).

The single most important conclusion to be drawn from time and work studies is that these influences will operate to some degree in any job situation. No arbitrary technique can provide a cook-book solution to improved task performance. Job and task procedures must be structured, the work-place and environment engineered, and available personnel trained and motivated in skills specific to the task.

Section C. Toxic and Drug Effects on Psychomotor Performance

1. Introduction

The physiological basis of sensation and psychomotor performance is the proper functioning of the central nervous system. Any drugs or toxic substances which affect the nervous system directly by stimulating or depressing the function of neurons, or indirectly by affecting their blood supply or metabolism or which affect the organs of special sense in any way, would be the concern of this conference because they ultimately affect psychomotor performance. In the basic review of toxic and drug effects presented at the Psychomotor Conference, all drugs or noxious agents which would fall under the above broad definition, understandably were not covered. Nor, was it the original intent of the paper to provide such broad coverage. Instead, presenting a limited range of information on toxic and drug effects gleaned primarily from industrial, military or private research sources, and grouped to be studied in relation to complex job behavior, was the objective of the review.

The reasons justifying this approach were essentially threefold. First, traditional studies of toxic substances and drugs have generally emphasized pathophysiological effects; remarkably little emphasis has been placed on psychomotor or behavioral effects. Second, concern with environmental pollution and the promiscuous use of drugs is expanding rapidly and attracting the attention and participation of the educational community; consequently, a summary of the somewhat complex behavioral relationships of drugs and toxic substances could be useful particularly to those educational specialists interested in the psychomotor domain. Finally, toxic and drug effects research generated by nonprofit research organizations and military-industrial groups is sufficiently unique and relevant to the broad objectives of this conference to warrant special attention and reporting. The summary and conclusions which follow reflect, in general, the above intent.

To eliminate redundancy, the Summary and Conclusions does not parallel the sequence of presentation by occupational classification, followed within the body of the report. Instead the data in the combined section have been related to psychomotor performance in its broadest context.

2. Summary and Conclusions on Selected Areas

(a) Behavioral Drug Research: A Molar Approach. Information resulting from research performed by industry, the military and nonprofit research organizations on the enhancement or impairment of behavior induced by drugs, toxic agents and unfavorable environments can be increasingly useful to educational specialists. These molar behavioral studies have special utility since they are done in relation to activities (job-contexts) that are important to man, highlight the necessity of including human behavior as a variable in toxic and drug effect investigations and support the need to use human performance as one of the principal bases for setting standards for environmental quality.

(b) The Psychopharmacology of Everyday Life. What Murphree, et al (1967), have called "...the psychopharmacology of everyday life, the study of the effects of numerous drugs with which people dose themselves, often chronically for many years, often without or even against medical advice, often for no discernible medical reason" must necessarily be a concomitant consideration in any investigation that studies contemporary man. This variable is of equal importance whether we study him in his terrestrial or extra-terrestrial habitats or in the context of the manifold occupations he may choose to earn his livelihood. We generally find in his medicine, liquor or kitchen cabinets the types of drugs reported in this review: ethyl alcohol, aspirin and related compounds, antihistamines, various tranquilizers or antianxiety drugs, stimulants such as caffine, pure or in tea or coffee, and amphetamine, tobacco and a host of others. We also must include the substances over which he has little or no control. The toxic as well as the life supporting gases that are found in his natural or artificial atmospheres and the harmful or nutrient substances that are dissolved in the food he ingests or the water he drinks. If the first order effect of the psychopharmacology of everyday life is ignored, second order studies on the behavioral effects of toxic substances and drugs can yield only questionable if not meaningless results. What effect the promiscuous use of drugs and prolonged habitation in a polluted environment will have, not only on performance, but on the more fundamental process of learning, is an intriguing question. It may become a requirement within the field of group and individual testing to standardize test instruments on populations described both in conventional terms such as age, sex, intelligence, etc., and equally important, on the psychopharmacology of their everyday life.

(c) Behavioral Effects Associated with Small Doses of Carbon Monoxide. The work by Schulte (1969) and Beard and Wertheim (1967) is of special significance to this conference. These researchers dared to investigate the effects of concentrations of carbon monoxide (CO) below 100 parts per million (100 ppm), an air quality standard that had long become frozen into common usage. Although it had been repeatedly stated that below this level there are no perceptible physiological effects, they undertook the exploration of this region looking for subtle behavioral changes and found them. In Schulte's study, the effects of exposures for varying lengths of time to an atmosphere containing 100 ppm of carbon monoxide were measured in a group of 49 healthy men between 25 and 55 years of age. This exposure produced levels of carboxyhemoglobin in the blood of the subjects ranging from 0 to 20.4%.

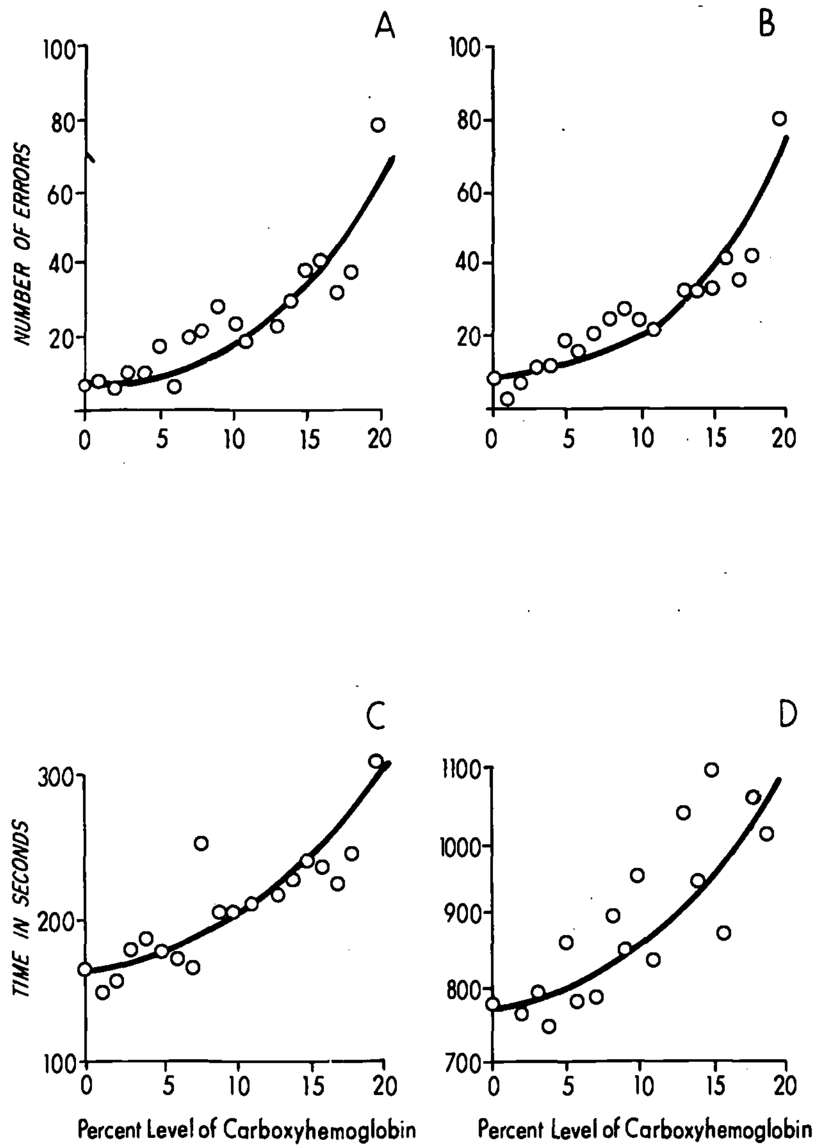
Impairment of function due to carbon monoxide occurred earliest in the higher centers of the central nervous system in that area (or areas) of the brain which controls some of the cognitive and psychomotor abilities. Impairment was detectable at levels of carboxyhemoglobin below 5%, and the degree of impairment increased with increasing concentration of the carboxyhemoglobin in the blood. Subjective symptoms did not occur nor were any physiological activities affected at levels of carboxyhemoglobin below 20%. Thus, alteration can and does occur at much lower levels of carboxyhemoglobin than those which are necessary to produce subjective symptoms or alter physiological signs. Furthermore, the degree of alteration in psychological abilities may be quite profound before any clinical signs or subjective symptoms are elicited. For example, there was a tenfold increase in number of errors in choice discrimination when the level of carboxyhemoglobin in the blood reached 20%.

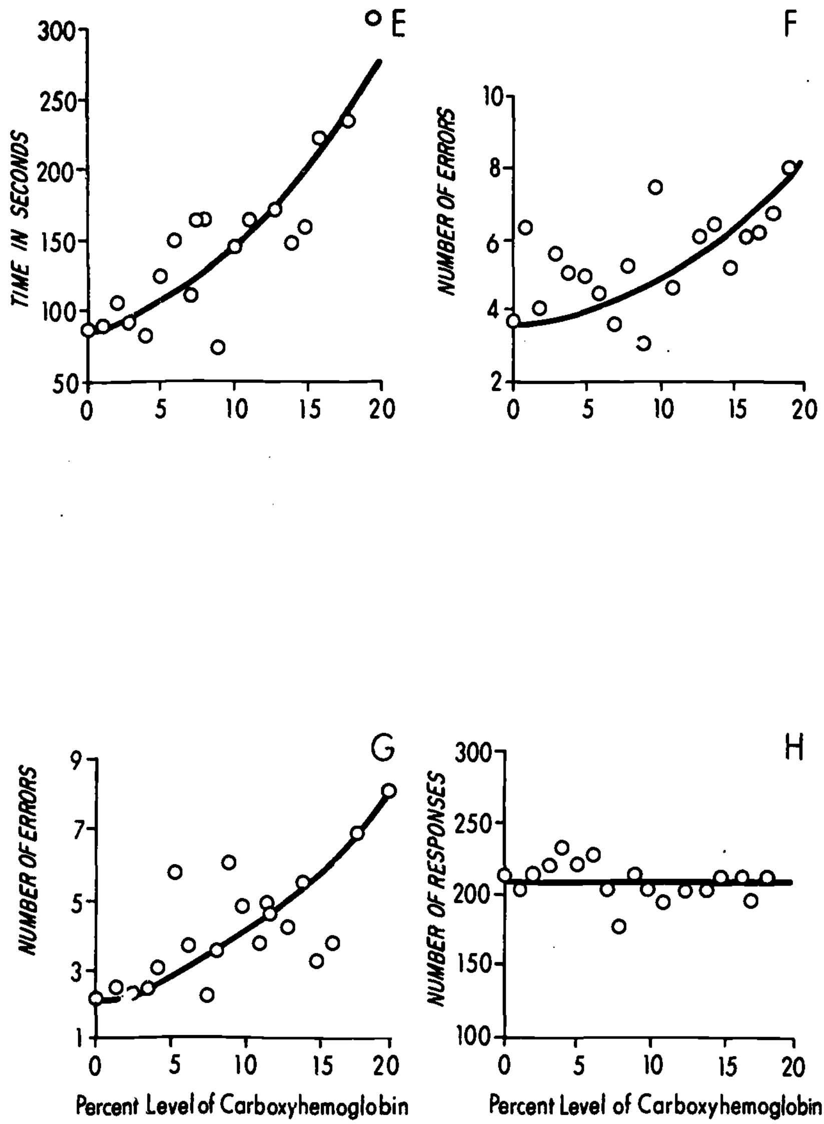
Table 5-1C gives the number of observations, the mean levels of response, the ranges of response, and the correlation coefficients between the particular measurement for each of these activities and the level of carbon monoxide in the blood. A graphic depiction of the results is illustrated in Figure 5-1C.

Table 5-1C — Mean of test response at each carboxyhemoglobin level

COHgb%	No. of Observat'ns	Response Errors Letter	Response Errors Color	Plural Noun Time	Arithmetic Time (Sec)	Arithmetic Errors	Crossing Time (Sec)	Crossing Errors
0.00	64	9.1	8.4	166	778	3.7	91	1.85
1.0	2	7.0	1.0	147	932	6.3	91	2.50
2.0	5	5.6	7.0	154	759	4.1	107	2.33
3.0	14	10.0	9.8	178	790	5.7	92	2.60
4.0	4	10.5	12.5	184	644	5.0	81	3.00
5.0	9	17.3	19.5	176	807	4.9	124	5.69
6.0	1	6.0	7.0	170	776	4.5	149	3.67
7.0	12	20.2	20.8	165	787	3.6	109	2.20
8.0	3	21.0	25.6	252	902	5.3	162	3.60
9.0	3	28.0	28.6	202	840	2.5	72	9.00
10.0	8	22.5	24.2	199	963	7.4	144	4.70
11.0	5	18.2	21.4	207	835	4.6	152	2.83
13.0	6	23.0	33.3	216	1,039	3.2	107	3.25
14.0	6	30.0	32.6	226	944	6.5	148	5.50
15.0	7	38.6	37.9	237	1,110	4.3	158	3.13
16.0	10	41.2	41.9	235	835	6.0	220	3.75
17.0	2	32.0	36.0	222	–	–	–	–
18.0	5	38.6	43.2	244	1,064	6.2	233	6.80
19.0	2	–	–	–	1,015	6.0	299	8.00
20.0	2	70.0	83.5	208	–	–	–	–

Figure 5-1C. Effects of Mild Carbon Monoxide Intoxication on Psychomotor Abilities (After Schulte 1963)




E
F
G
H
TIME IN SECONDS
NUMBER OF ERRORS
NUMBER OF ERRORS
NUMBER OF RESPONSES
300
250
200
150
100
50
10
8
6
4
2
9
7
5
3
1
0
5
10
15
20
Percent Level of Carboxyhemoglobin
Percent Level of Carboxyhemoglobin

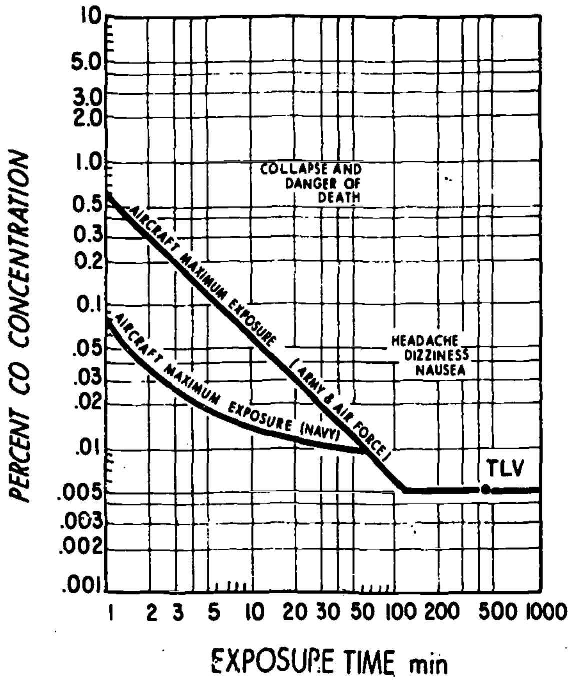
Beard and Wertheim (1967) decided that improvement was needed in the methods of setting standards of air quality. In establishing such standards, they proposed that the effect of various pollutants upon human performance should be considered. Toward this end, the effects of exposure to carbon monoxide upon the ability of 18 young adults, U.S. Army Personnel, to discriminate short intervals of time were studied. Deterioration of performance was observed. This occurred after 90 minutes at 50 ppm, and at proportionately shorter times after exposure to higher concentrations up to 250 ppm. The value of using a behavioral parameter to elicit impairment associated with small doses of a noxious agent was confirmed.

The results from their two studies obviously do not justify the immediate establishment of new air quality standards or threshold limit values, see Figure 5-2C for carbon monoxide values. Also, considerably more study is required before the significance of performance decrements they identified which are associated with low concentrations of CO, is fully understood. However, their work does point out the necessity to include studies on the effects of toxic agents on both simple and complex patterns of behavior as well as to apply experimental methods and techniques from the behavioral sciences: (a) to assist us in understanding the mechanism of their toxic action, (b) to generate data which may ultimately provide a more rational basis for setting safer standards of environmental quality, and (c) to help us in evaluating the effects of noxious agents upon man's capacity to both learn and to perform important psychomotor tasks.

The graph in Figure 5-2C shows the effects of carbon monoxide on man as functions of concentration and exposure time. Milder effects are shown as a lightly shaded band of exposure times on concentrations, while dangerous or lethal times and concentrations are grouped in the heavily shaded band. The solid lines are the exposure limits set by the military services for aircraft. The point marked at 0.05% (CO 50 ppm) and 480 minutes is the current Threshold Limit Value (TLV) for 8 hours-a-day exposure.

(d) Hypoxia and the Altitude Equivalence of Drugs. McFarland's (1963) gross summary of the behavioral and psychomotor changes (ranging from deterioration in the quality of complex coordination at 10,000 feet to loss of simple coordination at 17,000 feet) associated with reductions in oxygenation of the blood highlights man's problem in functioning in the aerospace vehicles' environment. Because of recognized human susceptibility to extremes of altitudes, builders of aerospace systems design within their environmental subsystems so that man will not be exposed to environments that may be physiologically damaging or physically painful, or contribute in any way to a reduction of his motivation and alertness, or lead to impairment of critical or safe operational performance.

The tissues we implicated as being the physiological bases for psychomotor performance, those of the central nervous system, particularly the brain and eyes, cannot function without oxygen. Since the only oxygen



stored by the body is what is actually being transported by the blood, oxygen breathing systems for aircraft must be furnished. It is these systems that make human flight and functions possible and less hazardous at otherwise impractical altitudes.

Even though provisions are made to protect man in space from environmental conditions outside the limits of his tolerance, he can still jeopardize his ability to survive or to use his faculties in operating his aircraft by deliberately or accidentally effecting changes in his own internal environment (see Wilks and Clark, 1959). The information presented on carbon monoxide by Hagen-Schmit (1965) and Allan and Allard (1961), alcohol by Harper and Albers (1964), McFarland (1953), McFarland and Forbes (1936) and Haldane and Priestly (1935) and smoking by Parmeggani and Gilordi (1952) and McFarland (1944) clearly indicates that these agents affect pilot performance by producing hypoxia, the general term denoting underoxygenation of body tissues from any cause. Alcohol produces this effect through respiratory depression while CO and smoking (which produces CO as a byproduct) form an abnormal compound in the blood, carboxyhemoglobin, which reduces the oxygen carrying capacity of the blood. Goren's 1966 study to test the hypothesis that alcohol could affect the uptake of CO in humans, possibly producing an effect more toxic than either alone fortunately was nonsupporting.

A significant implication for the performance or training of psychomotor tasks at sea level is that each of the substances discussed above has an altitude equivalence. For example, inhaling the smoke of three cigarettes at sea level can be equivalent of functioning at an altitude of 8,000 feet. Kelman and Crow (1969) conducted studies in which Ss performed two types of vigilance tasks at a simulated altitude of either 2,000 feet or 8,000 feet. Their results supported other findings that acute exposure to a simulated altitude of 8,000 feet impairs learning of a new task. Lilienthal and Fugitt (1946) specifically demonstrated the altitude equivalency of CO. The successful search for a drug that will aid accomodation to altitude may ultimately mitigate the altitude equivalence effect which can handicap the inveterate smoker. Although work by Cain and Dunn (1965) and (1966) suggested that the drug acetazolamide might aid accommodation to altitude, studies by Hartman and Phelps (1968) yielded no substantial evidence to support use of the drug for this purpose.

(e) A Partial List of Representative Behavioral Drugs. Table 5-2C (from Boren, 1966) is included because it represents an excellent summary of the important psychotropic drugs; that is, those with a psychological effect. Although the table covers many categories of behavioral drugs, this paper has essentially centered on the following three classes of drug effects: (1) Drugs having stimulant subjective and behavioral effects, (2) Drugs having depressant or hypnotic behavioral effects, (3) Drugs having tranquilizing or antianxiety behavioral effects. Tobacco really fits well in none, but rightfully falls in all of the above classes. We shall therefore give it the recognition it deserves by labeling it as one of the oldest and most widely used psychotropic drugs.

(f) Behavioral Studies and Setting Meaningful Standards of Air Quality. As citizens, educational specialists must do their utmost to combat the increase in air pollution and to support the many recommendations of the Environmental Pollution Panel of the President's 1965 Science Advisory Committee. One recommendation in particular for which their support as educators, more so than citizens, is required, states that "...efforts (should) be increased to establish the scientific bases upon which standards of environmental quality can be set." Among the "scientific bases" which can be considered in setting standards of environmental quality, evaluation of the effects of pollutants upon man's capacity to perform important tasks is unquestionably of prime importance to training.

This review contains convincing evidence of the deleterious effects that drugs and atmospheric toxic agents can have on complex human behavior in either artificial or natural environments. Educators involved in the psychomotor domain must insist that behavioral studies along with more classical physiological studies be used to provide data which may ultimately

Table 5-2C. A Partial List of Representative Behavioral Drugs[1] (From Boren, 1966)

I. Stimulants
  - d-amphetamine (Dexedrine)
  - methamphetamine (Methedrine and others)
  - methylphenidate (Ritalin)
  - Pipradrol (Meratran)

II. Antidepressants
  - A. Monoamine oxidase inhibitors
    - iproniazid (Marsilid)
    - isocarboxazid (Marplan)
    - nialimid (Niamid)
    - phenelzine (Nardil)
  - B. Other antidepressants
    - amitryptaline (Elavil)
    - imipramine (Tofranil)

III. Depressants
  - A. Tranquilizers
    - 1. Phenothiazine derivatives
      - chlorpromazine (Thorazine)
      - fluphenazine (Permatil or Prolixin)
      - perphenazine (Trilafon)
      - prochlorperazine (Compazine)
      - thioridazine (Mellaril)
      - trifluoperazine (Stelazine)
    - 2. Rauwolfia alkaloide
      - reserpine
    - 3. Muscle relaxants
      - meprobamate (Miltown or Equanil)
      - chlordiazepoxide (Librium)
  - B. Barbiturate hypnotics
    - pentobarbital (Nembutal)
    - phenobarbital (Luminal)
    - secobarbital (Seconal)
    - thiopental (Pentathal)

IV. Anticholinergics
  - atropine
  - benactyzine (Suavitil)
  - benztropine (Cogentin)
  - methantheline (Banthine)
  - scopolamine

V. Hallucinogens
  - lysergic acid diethylamide (LSD)
  - mescaline

VI. Analgesics
  - meperidine (Demerol)
  - morphine

[1] The generic name of the drug is given first, and the trade name appears second in parenthesis.

provide a basis for setting meaningful standards of air quality as well as an understanding of both gross and subtle behavioral effects of air pollutants. Also they should recommend that these behavioral studies be done in relation to job activities which are important for man or to segments of real-life activities (rather than abstract laboratory tasks) to ensure that results can be readily transferred and utilized in the world of vocational training.

(g) Drugs and Toxic Agents of Greatest Concern in Vehicle Operation, Aviation and General Use. Some of the medications mentioned by Dille and Mohler (1969) of greatest use and concern in general aviation include:

Analgesics. Acetyl salicylic acid (Aspirin) is used more often than any other over-the-counter drug. Toxic effects though rare are almost always associated with large doses. An example, related to psychomotor performance, is a reduced tolerance to hypoxia, mostly because of an increase in body metabolic rate.

Antihistamines. Undesirable behavioral effects of these drugs include drowsiness, inattention, confusion, mental depression, dizziness, decreased vestibular function and impaired depth perception. The combined (synergistic) effects of alcohol and antihistamines cause greatly impaired efficiency and judgment.

Motion Sickness Medications. All of these readily accessible compounds have sufficient side effects to limit their use: drowsiness, dizziness, blurred vision. In combination with alcohol they severely depress the central nervous system (CNS).

Amphetamines. These are cerebral stimulants which diminish a sense of fatigue or delay its onset tending to force the body beyond its natural capacities. Over-dosage is reported to produce nervousness, impaired judgment and euphoria.

Tranquilizers and Sedatives. These substances have measurable effects on alertness, judgment, efficiency and over-all performance. They are generally prescribed without due concern for the patients occupation and may cause severe unsuspected depressant effects in combination with alcohol.

McFarland and Moseley's (1954) work, which was cited extensively in the body of the review, leaves no doubt as to the critical relationship between alcohol, tobacco and drugs and driver performance. The effect of these agents is briefly summarized below:

Alcohol. Contrary to popular belief its action on the nervous system is that of a depressant rather than a stimulant. Heavy imbibers manifest poorer performance in muscular skill, sensory acuity, memory judgment, and other psychological functions.

Tobacco. Excessive smoking may significantly influence a driver's night vision since a distinct rise in the visual threshold can occur after each cigarette. Although various experiments have shown little effect of tobacco on complex psychological and mental functions, the impairment of night vision is especially significant for night driving since dim illumination imposes such a strain on visual functions.

Other Drugs. (a) Bromides and barbiturates: sleep-inducing drugs which may continue to have an effect, i.e., an inhibitory action on the CNS, beyond the period of sleep. (b) Antibiotics: streptomycin, as an example, may produce reactions such as loss of balance, dizziness, ringing in the ears and deafness. (c) Dramamine and Antihistamines: give rise to drowsiness. (d) Caffeine: stimulates the CNS, (e) Benzedrine: markedly stimulates the CNS resulting in elevation of mood, euphoria, decreased ability to concentrate and sleeplessness.

The results of an investigation by Heimstra, Bancroft, and Dekock (1967) on the effects of smoking upon driver performance showed no significant differences between smokers and nonsmokers in the various measures involved in a driving device. However, deprived smokers showed significantly more tracking errors and vigilance errors than subjects in other groups and data from a mood scale indicated increased feelings of aggression in the deprived smoker and nonsmoker groups, but not in the smoker group. The authors review of other studies dealing with the effects of smoking on psychomotor performance indicated that the typical initial effect of tobacco appears to be a decrease in precision of finely coordinated movements, a decrease in overall efficiency and either an increase or decrease in speed and the number of errors, depending on the form of tobacco and its mode of administration.

Murphee, et al (1965), whose studies of the quantitative electroencephalographic effects of smoking revealed it to be a stimulant rather than a tranquilizer, received indirect support for this conclusion from questionnaire findings. In the latter survey, Heimstra, Allusi and Adams found that a large percentage of Ss queried increased their smoking to alleviate or counteract fatigue during long driving sessions.

The Katz and Forbes (1957) review on the effects of analeptics concluded that, in general, the results of small doses of compounds such as Dexedrine under proper usage appear beneficial, although certain cautions and limitations are definitely indicated. Their primary concern was that there were relatively few field studies which reported beneficial results especially on attitude and prevention of decrement from fatigue. Most of these so-called field studies made measurements in the laboratory after field performance or else simulated the field performance in the laboratory. They echoed the concern of the industry representatives to this conference in their observation that apparently very few actual studies of drug effects involving practical tasks, such as the performances which are critical in the complicated behavior required for automobile driving, are routinely carried out in the field of drug research.

Ganslen, Balke, Nalge and Phillips (1964) completed an investigation predicated on the basis: (a) that drugs used for general therapeutic purposes, such as the tranquilizers of the meprobamate group may affect the work capacity of normal Ss; (b) that certain drugs, considered as aide to heart function, may materially alter the working capacity of normal Ss; (c) that the biological effects of the drugs under investigation were such that their use should be indicated or contra-indicated for persons in certain occupations who might be subject to extensive physical demands. The authors felt that the untoward affects of Equanil, the tranquilizer, contra-indicated the use of meprobomates in general because of their sedative effects and the extent of the vasomotor system depression they produce. The caffeine-metrazol combination and Recordil both improved working capacity. However, Recordil made the subject feel subjectively "keyed up" for about 12 hours after ingestion, and also produced belated faint anginal sensations of short duration. The caffeine-metrazol combination appeared to be a closer approximation to the ideal anti-fatiguing medication, i.e., one which would enhance working capacity without noticeable psychological side effects. Benzedrine and other amphetamine compounds were not judged acceptable. The authors concluded that these compounds unquestionably have potent psychic energizing effects, but the apparent improvements in working capacity with these substances are more often the result of motivational factors than physiological improvement.

Lastly, toxic agents studied in considerable detail, particularly for their physiological effects, included oxygen, carbon dioxide and carbon monoxide. Oxygen toxicity was well verified in men who had breathed high concentrations of oxygen at normal pressures; pulmonary oxygen toxicity can also be a problem in flight. High concentrations of oxygen act principally on the lungs and the central nervous system. Central nervous system effects consist of confusion, irritation and even convulsions (see McFarland (1953) and Haldanne and Priestly (1935)).

Carbon dioxide in relatively low concentrations causes subjective reactions, principally a feeling of suffocation. High concentrations may cause depression of higher centers evidenced as confusion, loss of consciousness or even convulsions (Gibbons, Franklin, Jones and Wamsley (1969) and Schaefer (1961)).

Carbon monoxide toxicity quite obviously has been extensively studied and its effect reasonably established; see Roth, Teichner and Mirachi (1968). All evidence indicates that its only biological effects are those resulting from oxygen transport. The time-concentration relationships for carbon monoxide are well known. Levels for community air pollution have been set for carbon monoxide and reflect recognition that persons who are heavy smokers or who have impaired cardiorespiratory physiology are especially susceptible. There is a paucity of data for the effects of concentrations of carbon monoxide below 100 ppm since it is stated that below this level there are no perceptible physiological effects. Recent explorations, Schulte (1963) and Beard and Wertheim (1967), of this region have uncovered subtle behavioral changes in both animals and humans. Although these findings are important, much remains to be done before the significance of performance decrements associated with low concentrations of CO is fully understood.

(h) Theoretical Implications. Miescher-Rusch in 1885 attributed an angelic role to carbon dioxide when he stated "... over the oxygen supply of the body, carbon dioxide spreads its protecting wings." Since that time a number of physiologists have either again suggested or demonstrated that carbon dioxide does indeed partially protect the body from the effects of hypoxia. It is our contention that within the world of the behavioral sciences the "zeitgeist" is right for a comparable statement. Paraphrasing the beautiful prose of Miescher-Rusch it could be stated: *Over the learned skills within the organism, the mechanism of overlearning not only increases the resistance of these skills to forgetting, but also reduces their susceptibility to drug influences (and to effects of environmental factors, as pointed out elsewhere in this paper).* There is no question that the Miescher-Rusch statement alone will survive if only on its literary merit. But, another look at the data does lend some credence to our badly worked bit of prose.

Recapitulating, support for the statement is found in several of the studies previously discussed. The Chiles, Alluisi and Adams (1968) study for example, in which Donnatal (an antispasmotic) and Chloropheniramine (an antihistamine) were administered to "over-trained" Ss, indicated no drug effect. The authors state they recognized from the beginning that the dosages of the two drugs were marginal in terms of producing a measurable effect on performance, but were consistent with the need to determine the effects of ingestion of typical amounts of the drugs in question. The other factor that the investigators assumed tended to minimize the possible effects of Donnatal and Chloropheniramine was that they were "highly trained" for their "jobs." In line with our hypothesis, we would take only minor issues with the authors' explanations. Their result would appear equally explainable by positing that the overlearning and not the "typical amounts of the drugs" ingested was primarily responsible for their benign effect.

In an experiment by Kelman and Crow (1967), Ss performed two types of vigilance tasks at a simulated altitude of 2,000 ft. or 8,000 ft. With the easier test there was no significant difference between performance at 2,000 ft. and at 8,000 ft. With a more difficult test, the Ss initial performance was significantly worse for the hypoxic group, compared with the control group at 2,000 ft. However, when both groups became familiar with the test, i.e., overlearned it, the differences was not statistically significant. In this case, it could be said that the mechanism of overlearning counteracted the deleterious effects of hypoxia.

Finally, in a study by Gibbons, Franklin, Jones and Wamsley (1969) whose purpose was to evaluate performance of a complex psychomotor task during exposure to 38 mm Hg PCO_2 in air at sea level, there was no apparent degradation in the Ss' ability to perform a primary task consisting of a motor response to a visual stimulus. However, there was indication of degradation in the performance of a secondary task. If we assume that the primary task was the better learned of the two tasks, the results are explicable within the framework of our hypothesis.

In brief then, increased mastery of psychomotor skills would appear to trigger some type of internal mechanism that reduces their vulnerability to hostile external environments, or to drugs. In the case of drugs, it could be hypothesized that this effect could apply to classes of medicinals that tended to either enhance or degrade performance. The practical significance of the former inference is clear: if highly trained Ss are resistant to the enhancement effects of drugs, their use for enhancement purposes is both wasteful and inefficient. The relationship between drugs that degrade performance and the mechanism of overlearning will be examined later in this discussion.

If a skill is not overlearned, is it possible that drugs in therapeutic doses could serve to either enhance or have no demonstrable affect on performance? Astronaut Cooper's frequently referred to ride from space may fit the criteria for enhancement of a moderately complex skill which no amount of simulation practice could develop into a completely automatic response habit, i.e., reentry occurs too infrequently in the life of an astronaut to become a completely automatic response.

Cooper did use 5 mg. of amphetamine as a psychic energizer during his last orbit and his subsequent near perfect reentry and landing could be considered a textbook description of one of its uses: to enhance performance under moderately high task demands. Its effective use also served to accelerate a wide range of drug research to prevent, mitigate, or compensate for other mental and physical deteriorations that might occur in space. Table 5-3C represents the first approximation of a program subsequently presented.

This table from Schmidt (1965) summarizes the special indications for drugs at the various flight stages, the general nature of the drugs to be considered, the purpose of such medication, and some of the undesirable effects which could be anticipated according to information then available. The final column of the Table identified the type of simulation in which the studies could be carried out. Because of the pressure of time, removing the causes of the physical and mental deterioration noted in Cooper's flight through engineering advances was not possible. An appropriate medicine chest, however, did evolve as an acceptable alternative and contributed immeasurably to the success of the Apollo flights.

Performance decrement as a residual effect of secobarbital was reported by McKinzie and Elliott (1965). Their results demonstrated that 200 mg. (3 gr.) of secobarbital produced significant decrement in a simulated pilotage task 10 hours after ingestion and this effect persisted throughout the 12 hour "mission." Furthermore, this amount of secobarbital both delayed and attenuated the effect of d-amphetamine given during the "flight" to combat fatigue.

Table 5-3C Pharmacology of Man in Space: Pertinent Experimental Studies (From Schmidt, 1965)

Space	Special indication	Drugs to be considered	Purpose	Possible undesired effects	Nature of simulation
Preflight	Test individual responses to drugs that may be used in flight	All drugs selected for medicine chest	Detect adverse reactions Guide to dosage, timing interferences, etc.	Annoyance to astronauts	Ordinary laboratory environment
Preflight isolation	Prevent infection during flight; adapt to diet, air, etc.	Antibacterial and antiviral agents; nasal and bronchial decongestants	Minimize risk of infection during flight (pathogens of resp. and G-I tracts) minimize resp. obstruction during takeoff	Changes in intestinal develop sensitivities (man) and resistances (microbs)	Space cabin, diet, and atmosphere
Launch	+Gx-pain, dyspnea, cough Anoxemia Atelectasis	Cholinolytics (secretions, dilate bronchi) Pul. vasodilator, bronchodilator	Minimize degree and duration of anoxemia; keep resp. passages open; reduce pul. edema	Atalectasis minimized by high N, inhaled but at cost of aggravated anoxemia	Centrifuge
	Resp. obstruction Elevated pul. art. pressure (Pulmonary edema?)	Isoproterenol		Cardiac stimulation	
Space flight	Persistent atelectasis	Antibiotics and antiviral agents	Prevent pneumonia	Same as before flight	Space cabin, diet, and atmosphere
	Motion (rotation)	Antiemetics or tranquilizers	Prevent nausea and vomiting	Somnolence, inattention	
	Diarrhea, distention, constipation	Absorbents, food supplements Cellulose, petrolatum	Counteract abnormal diet	Contamination, difficulties over waste	
	Disturbed sleep-rest cycles	Barbiturates; —OH butyrate; analeptics	Provide protect against radiation; arousal when needed	Inattention to essential tasks; add to deterioration on reentry and landing	Centrifuge
	Care of skin	Cleansing, toughening, and antiseptic agents	Prevent maceration or ulceration. minimize waste accumulation; prevent conjunctivitis; minimize deconditioning of circulation	Contamination of atmosphere; drug dermatitus conjunctivitia	Space cabin, diet and
	Care of eyes	Emollients and antiseptics			
	Weightlessness	Hypotensives to exercise baroreceptors		Circulatory disturbances	
	Toxic radiation	Aminothiols Narcotics Chloropromazine Serotoxin, Reserysine	Protect against brief exposures (Van Allen belts, solar storms, etc.)	Add to deterioration prior to a re-entry and landing	

Table 5-3C (Cont.)

Space	Special indication	Drugs to be considered	Purpose	Possible undesired effects	Nature of simulation
Deceleration for re-entry	As for launch but more urgent (higher velocity, deteriorated subjects)	Decongestants of nasal and resp. passages Cholinolytics Antihistaminics Isoproterenol	Minimize resp. obstruction and pulmonary hypertension	May upset fluid balance disturb vision and depress CNS; may aggravate postural hypotension	Same as above
Disembarkation	Cardiovascular deconditioning (orthostatic hypotension)	Time medication with this in mind	Maximize changes of survival	CNS effects (may be desirable)	Same as above
	Somnolence	Ephedrine, etc.		Intravenous injection required	
	Atelectasis (Anoxemia)	Levarterenol, methoxamine, or angiotensin for shock Bronchodilators		Intravenous injection required	
	Landing in hostile region	Protection against amebiasis, malaria, typhoid, meningitis, cholera, etc.		Perhaps avoidable addition to preflight tribulations	
Any stage except acceleration and deceleration	Minor aches and pains Diarrhea Trauma Burns	Aspirin, APC, etc. Absorbents Antiseptic Analgesic Anasthetic	PRN		Space cabin and atmosphere

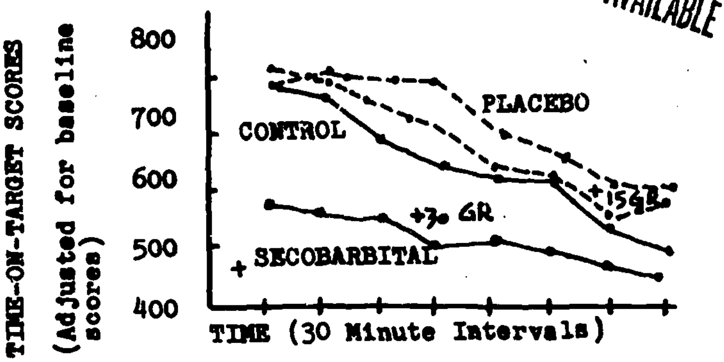
Hartman and McKenzie (1966) wished to confirm the previously observed effect of 3 gr. but without the complications of an extended mission and the use of d-amphetamine as a stimulant. The study appeared to clarify the "hangover" effect of secobarbital, reported in the earlier study, relating it to dosage. The "hangover" effect is characterized by degraded performance and subjective feelings of lack of coordination and sleepiness, see Figure 5-3C and Figure 5-4C. With 3.0 gr. of secobarbital these effects were seen 10 hours after drug ingestion and persisted for a considerable length of time. These findings were remarkably consistent with those of the previous study in which degraded performance was present throughout the entire 12 hours "mission." No degradation in performance occurred from the administration of 1½ gr. of the drug, Figure 5-3C.

Since the therapeutic dose of 1½ gr. of secobarbital had no effect on performance, can we not assume that the principle we have espoused, i.e., the moderation of impairment (in this case of a CNS depressant) by an overlearning mechanism, was conclusively demonstrated by the result? However, some 10 hours after ingestion of 3.0 grains of secobarbital, degraded psychomotor performance was a pronounced residual effect. Could it be that the double dose produced marked impairment because the skill had been inadequately learned? More specifically, is it possible that the relevant skill had not been learned to a criteria that would invoke the overlearning mechanism to serve as a countermeasure against the more potent depressant?

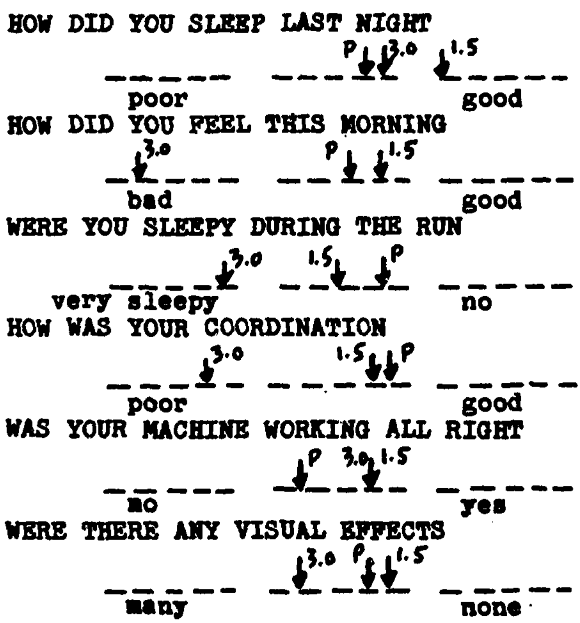
The Tang and Rosenstein (1967) study provides, in part, additional support for our general hypothesis. Both alcohol and dramamine alone, respectively, had no or small performance decreases. Their combination, however, produced much larger performance decrements. Perhaps the skill had not been sufficiently learned to resist the synergistic effect? That a combination of alcohol with Dramamine, a common anti-motion sickness remedy, produced much larger performance decrements than each alone has serious practical implications. As Dramamine is a relatively short acting drug (3-4 hours), other long-acting CNS depressant drugs when combined with alcohol could produce much longer and serious performance decrements, with serious resultant consequences, in all types of users, especially ground vehicle and aircraft operators.

Extrapolating from our data, is it possible that principles similar to those we have just discussed affect the general use of drugs in the community? For example, the driver of 25 years who habitually drinks may be intoxicated but still gets his car home. The socialite on a diet of "pep-pills" and "dolls" may tempt fate with her driving for years but still reaches her destination safely. We ask: Is not the mechanism of overlearning in these cases spreading its protective wings?

The basis for still another hypothesis would appear to come from Howard's (1965) test of a new central stimulant, 5-phenyl-2-imino-4-oxo-



Degraded psychomotor performance as a residual effect of secobarbital administered 10 hours before beginning of the experimental period. (From Hartman and McKenzie, 1966)



C CONTROL
P PLACEBO
1.5 1½ gr SECOBARBITAL
3.0 3 gr SECOBARBITAL

Graphic representation of mean subject debriefing responses by treatment groups in study on the residual effect of secobarbital on psychomotor performance. (From Hartman and McKenzie, 1966) oxozoliddne. In therapeutic dosage, the stimulant significantly reduced the impairment that had developed in a vigilance task and was actually more effective when the level of impairment was higher. Progressively higher doses, however, had less effect on the impairment and eventually accentuated the condition.

An explanation of these results can be given if we adopt the point of view that the human organism is essentially a data processor and ascribe to the new stimulant some of the known properties of existing stimulants. We will choose amphetamine as our model since it is known to be capable of enhancing performance under moderately high task demands, an effect the new drug displayed in Howards's study. Returning to the paradigm of the human as a data processor, it could be said that moderate doses of the stimulant ensured optimal functioning of the human data processing mechanism by not exceeding the channel capacity of the human processor.

Why then did we experience performance decrement with progressively higher doses of the new stimulant? The explanation may be this: the decrement in performance that occurs could simply be a function of input queuing and channel capacity limitations in the human. Higher doses of the drug in question have the effect of speeding up the data processing. Next, queuing results because of channel capacity limitations in the organism. Queuing, in turn, produces decrements in performance as a result of short-term storage, i.e., inputs are lost while awaiting data processing.

The hypothesis may be completely invalid but still have considerable pragmatic value. The amphetimines, for whatever reason, should be given in moderate doses if they are being administered to enhance either cognitive or psychomotor performance. Massive doses of the drug, besides causing toxic physiological effects, can be expected to exacerbate rather than to enhance human performance.

The study by Johnston (1968) also had interesting theoretical implications for enhancing psychomotor performance that merits a special review. Johnston's experiment suggested that tobacco smoking degrades vision; or stated in a more positive manner, that habitual smokers who reduce their smoking or abstain from smoking may markedly increase the size of their visual field (i.e., peripheral acuity) and improve their search performance. To the military pilot who smokes, the training he receives in search performance may be negated in part by his smoking. When search performance must be learned or proficiency in this skill maintained as part of any task, gains completely independent of the training situation, selection of the trainee, or choice of a training device may be effected by manipulating an external variable such as smoking. The gain in performance brought about by the cessation of smoking is a bonus pure and simple, brought about in the most cost-effective manner possible; an overlay on top of gains normally produced by the above and other costlier procedures, e.g., human engineering, maintainability, etc.

The pharmacological future as it relates to performance enhancement is bright. With adequate research, we may be on the threshold of legitimately recommending for use drugs that could greatly augment human intrinsic capacities. The tragedy of our times is that our eager young people seem unable to wait for future research to catch up to their present need and have filled the vacuum by resorting to self-experimentation. Accelerated research in the area of behavioral pharmacology may be an expedient means of solving not only the social problems associated with promiscuous drug use but also the technological problem of finding safe effective drugs that can be judiciously used to enhance human performance.

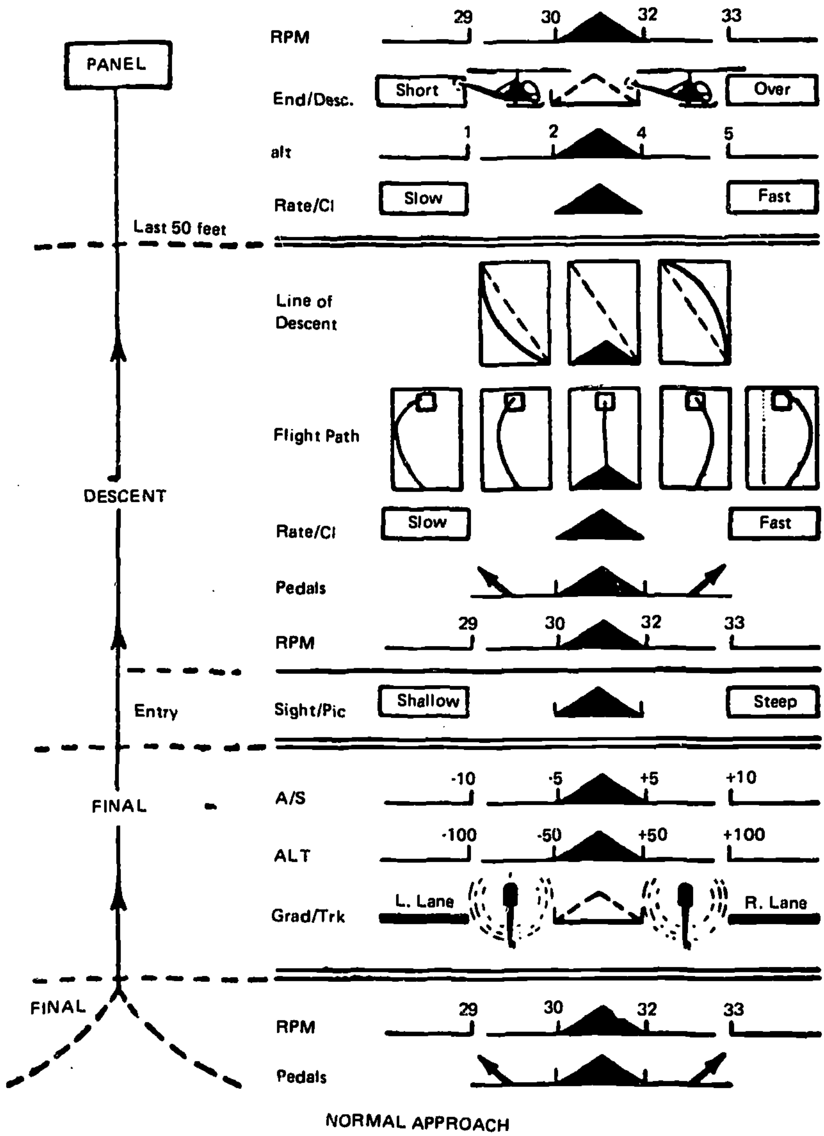
Section D. Task Loading: A Way Of Viewing Systems Operator Performance

1. Introduction

In the context of the aerospace industry, the definition of the tasks in which aircraft and space vehicle operators and maintenance personnel must engage, and the time in which these tasks must be accomplished, constitute a major segment of the activities of the human factors specialist. Further, a substantial research and development effort is directed to methods of reducing high, or impossible task loads. The subjects of this R&D effort include improvement in the information and control interfaces between man and the equipment he is operating, improved allocation of tasks among crewmen, improved selection and training of personnel, and increased automation. One effect of this considerable attention to the "task loading" problem has been development of a point of view with respect to the psychomotor effectiveness of operators, which we are calling the task loading view. We believe this view may be useful in a much broader context than system operation and maintenance, and for this reason present it to Instructional Media specialists for their consideration.

To illustrate high task loading, a segment of a relatively objective instrument developed by the Human Resources Research Office in the late 50's for measuring helicopter pilot flight proficiency is presented in Figure 5-1D, taken from Greer, Smith and Hatfield (1959). Check pilots, riding with the student, recorded the selected elements of the student's performance on this form, as the student performed. The entire sequence, from initiation of "final turn" at the bottom of the record sheet, to "termination of hover" at the Panel, required an average of 12 to 15 seconds. Each element represents an action or composite of actions to be performed by the student during the maneuver, and occupies fully both hands and feet, as well as visual and auditory capabilities. But task loading in this context is not only the number of tasks the pilot must engage in of course. It is the skill and efficiency with which he accomplishes them. For the early student, the load far exceeds his task handling capacity. For the instructor, his capacity equals or exceeds the task load under almost all conditions. This is one way of viewing level of training and skill. Broadening this task loading view, and taking it as in integrating concept, a variety of factors impacting on psychomotor performance effectiveness can be taken into account. These factors include, in addition to the individual's inherent ability and the skills he has acquired through training: his physical and mental state during performance; the environment in which he is performing; the adequacy of the operator equipment interfaces he must perform with; and the number, complexity and compatibility of tasks required of him in a

Figure 5–1D Sample Record Sheet From 1958 Version of the Intermediate PPDR



From Greer, Smith, Hatfield (1959)

finite time period. Each of these factors may be described in terms of their impact on task handling capacity of the individual as he performs.

2. Summary and Implications for Instructional Media

With this task loading point of view in mind, the following generalizations are offered, in the context of the psychomotor domain, with the suggestion that they may apply to the broader instructional context.

We may assume that the instructional process imposes an additional task on the student of attending to, interpreting and applying directions from his instructor, on top of the task load capacity limitation due to his underdeveloped skills. Thus, in the learning of complex psychomotor skills, in which the student must perform part or all of them at the same time he is being instructed, it is all important to recognize that instruction is actually imposing an additional task load, which may very well be the first task element which is dropped out as the overload necessitates the student's reducing the scope of tasks he handles.

When a student is learning to operate a piece of equipment (aircraft, car machine tools, etc.), and there are identifiable deficiencies in the man-equipment interface, these deficiencies should be identified prior to developing the training curriculum. Then they should become the topic of special emphasis, or separate part-task training, in planning and executing the training program. An example of a serious equipment deficiency is the combination of the RPM indicator and the RPM control in the light observation helicopter of the late 50's and early 60's. The range within which RPM must be controlled is very narrow, and this range was difficult to read on the instrument due to instrument design. To compound the problem, the RPM control involved a complex, non-linear control action in relation to the actual change effected in RPM. As a result, it was estimated training was increased by at least 10 flight hours due to this man-machine interface deficiency. This type of problem should be identified and singled out for special attention in the development and execution of the training program.

A corollary to the interface deficiency problem described above is the fact that, where possible, both training and performance requirements should be among the major factors impacting on the design of the man-machine interfaces of new systems. Undoubtedly, the added helicopter student training costs (at a minimum of $35 per hour), to say nothing of lost equipment and unnecessary washouts, far exceed the costs that would have been associated with the relatively simple fixes required for the RPM indicator and control.

Frames of reference used to judge trainee proficiency during and at the end of training should be standard, or confusion and unnecessary self depreciation on the student's part may severely impede training progress. This is particularly important, and most difficult to accomplish, in training of complex psychomotor skills.

The degree to which evaluative frames of reference can vary from individual to individual is dramatically indicated in Table 5-1D, in which the average of the error percentages over ten or twenty rides is presented for each of six check pilots, two of which helped build the special evaluation system illustrated in Figure 5-1D. The other four were only partially trained in its use. Note that Pilot 3 attended little to pedal and ground track control, but was big on altitude control, whereas Pilot 4 worked pedals and ground track hard, and attended little to altitude. In the development of the application of this check ride system, these types of data helped improve both instructor and check pilot standardization. Without such standardization, student confusion and loss of confidence as well as much wasted training time results. Improving standardization of evaluative frames of reference apparently improved training effectiveness significantly in the helicopter training program.

Trainee fatigue can be interpreted as reducing his task load handling capacity, and as such is an important factor for the instructor and the training program scheduling to take into consideration. Failure to do so will result in wasted training time at the least, and possible proficiency regression due to poor mental attitude or conviction of inadequacy on the part of the trainee.

Among the many media considerations possible for informational transfer between man and the system he is operating, use of auditory displays in lieu of, or as supplements to, visual displays may substantially increase the operator's task load handling capacity. The same considerations, that is taking advantage of each of the sensory media for appropriate information transmission, may also apply to training.

This point is made well in a series of studies by Hodgson (1966) in which relative effectiveness of visual versus auditory versus visual-plus-auditory presentation of flight control information was evaluated with respect to both flight control efficiency and external visual search. The summary data is presented in Figure 5-2D. The two graphs on the left side of the figure represent tracking (flight control) efficiency. The three dots in the upper left quadrant of these two graphs represent subject performance with the three methods of control information display, when the subjects were tracking only (no simultaneous search) on their last training day. The graphic data represents what happened to their tracking efficiency when they were required to both track and search. Note that the same relative order (Audio + Visual best, then Visual then Audio) obtained but that over-all tracking efficiency in both vertical (controlling nose altitude) and horizontal (controlling directional altitude) degraded between 4 and 9 percentage points when the search task was added. Of particular interest, however, are the effects of the three display modes on Search performance,

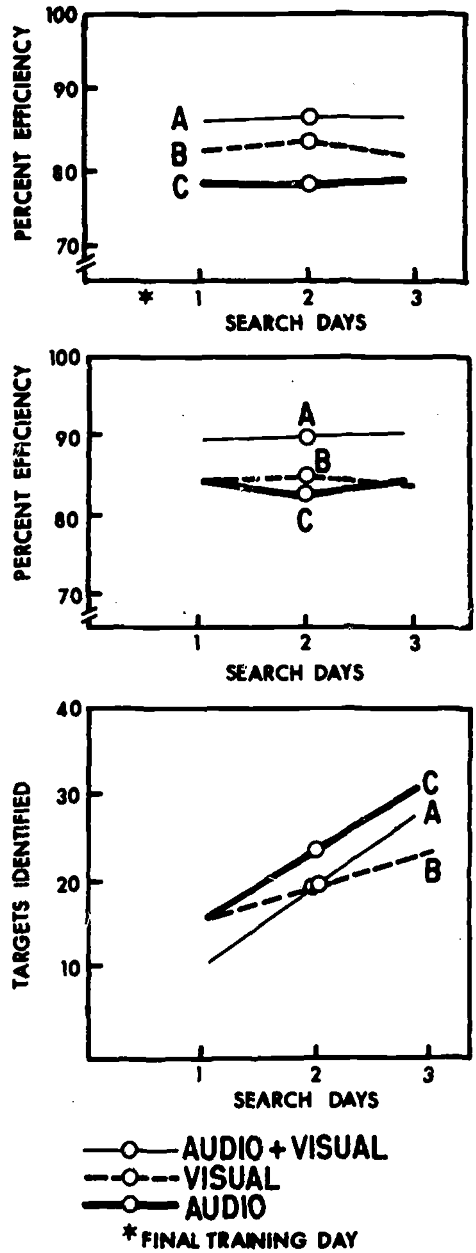
Table 5-1D. Mean Percentage of Errors Recorded for Selected Items and Mean Over-All Scores by Check Pilots for the Intermediate PPDR's, 1957

	Check Pilots					
	PPDR Experts		PPDR-Oriented			
	1	2	3	4	5	6
Number of Rides	20	20	10	10	10	10
Mean Percentage of All Errors Possible for[1]:						
Pedals	21	19	5	29	17	20
RPM	37	37	10	36	36	17
Air Speed	38	47	21	33	38	25
Altitude	26	22	19	9	14	8
Ground Track	15	13	5	24	15	11
Mean PPDR Item-Weighted Score	75	74	85	72	76	83
Traditional Grade[2]	40	30	100	0	30	60

[1]These scales constituted over half of the items on the PPDR.

[2]Based on the percentage of "average" and "above average" grades given. Other options were "below average" and "unsatisfactory." The PPDR was not referred to in assigning the traditional grades in 1957.

AUDITORY DISPLAY AND VISUAL SEARCH

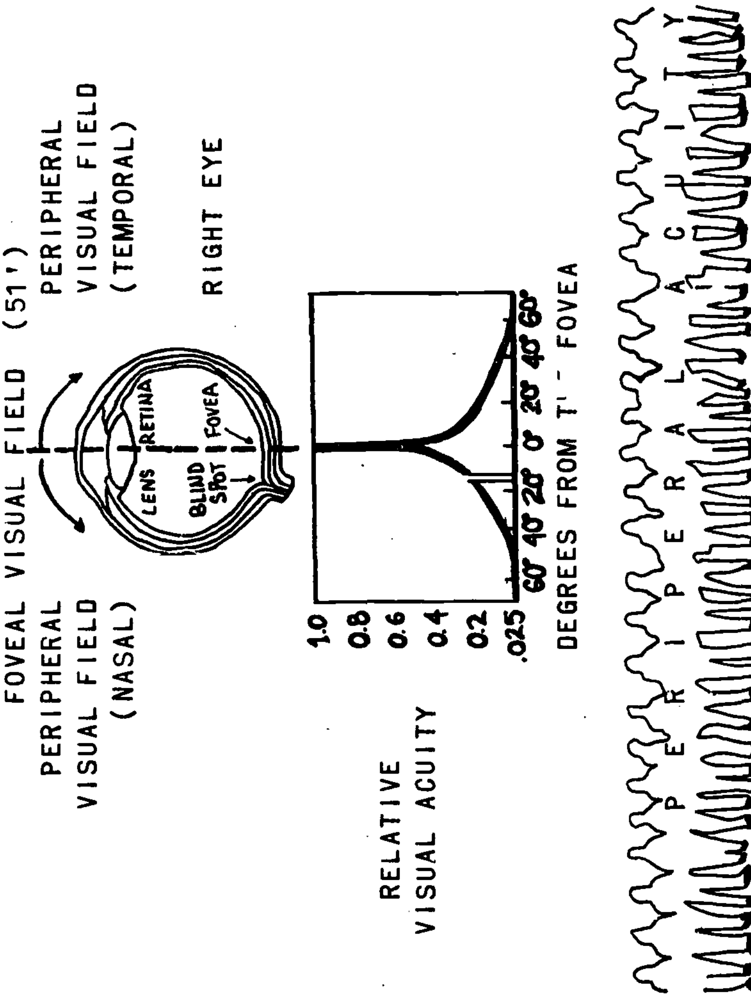


represented in the right hand graph in Figure 5-2D. It appears that the Auditory display relieved the visual mode sufficiently from the control task to allow him to engage more effectively in search. The subjects, overall, preferred the combined auditory-visual mode of control information presentation, stating that the auditory signal served as a warning, while they were searching, that they should work their control task. They would then use the visual display for rapid correction (which was easier and faster to use than the auditory display), and once their control problem was worked, they could revert to visual search with confidence. This represents a reasonably sound use of man's two primary information acquisition senses in a complementary fashion, an objective all too seldom considered or met in information presentation systems where the information rate is high.

The primary sensory mode, used both in performing and learning complex psychomotor skills, is vision. A characteristic of visual capability largely ignored primarily due to ignorance, is peripheral vision. In tasks requiring acquisition of relatively small amounts of critical information from a wide visual area in a limited time period, training directed to the value and use of peripheral vision might increase task loading handling capacity. Carefully planned programmatic research is necessary to further clarify the application and value of this type of training emphasis.

Peripheral vision is defined as that visual capability outside of the "foveal" area, the point on the retina with the highest acuity and subtending approximately one degree of arc. This is presented schematically in Figure 5-3D, on which the relative visual acuity, as a function of displacement in degrees from the fovea, is shown.

A study of Johnston (1965) was directed to the question of the role of peripheral acuity, out to a distance less than 15 degrees from the fovea, in visual search. The motivating concern was that literally all practical measures of visual acuity are directed to foveal acuity only. She measured foveal and peripheral acuity of 36 subjects and asked them to participate in a pair of timed search tasks. Despite a rather severe restriction in the range of foveal acuity, a wide range of peripheral acuity was found and it was shown to correlate significantly with search performance, particularly when the display size for the search task was large, and when the search task was for something different in a sea of sameness, (Pierson Product Moment correlation of .49). Additionally, peripheral acuity was found to correlate with the same subjects' scores on an Air Force Speed of Identification test to the extent of -.50. Correlation with foveal acuity was only .32, but this is probably due in large part to the range restriction in foveal acuity among the subjects. These findings need further substantiation by well controlled, programmatic research, but suggest that: (a) peripheral acuity should also be measured as an indicator of visual effectiveness for selection purposes and perhaps for identifying student problems attributable to visual defect, and (b) training to attend to the information available in the periphery


FOVEAL VISUAL FIELD (51')
PERIPHERAL VISUAL FIELD (NASAL)
PERIPHERAL VISUAL FIELD (TEMPORAL)
LENS
RETINA
BLIND SPOT
FOVEA
RIGHT EYE
RELATIVE VISUAL ACUITY
1.0
0.8
0.6
0.4
0.2
.025
60° 40° 20° 0° 20° 40° 60°
DEGREES FROM T' - FOVEA
PERIPHERAL ACUITY

may well be a useful method of increasing the task load handling capability of people engaged in acquiring and processing information from a wide field. Learning to attend to the periphery to a greater degree may well be a major factor in learning "speed reading" for example.

In this section, we have attempted to present and illustrate in a very brief discussion a Task Load point of view, which emphasizes the interaction between the number of simultaneous tasks that are being imposed on an individual in a finite time period, on the one hand, and the individual's task load handling capacity, on the other. Regarding the number of tasks, certain considerations may well render these tasks more difficult, such as task incompatibility and poor man-equipment (i.e., display and control) interfaces. Regarding the performing individual, his capacity may be influenced greatly by his inherent abilities and characteristics, his level of training, his mental and physical state (due to amount of sleep, use of drugs, etc.), and the environment in which he is performing. We find this point of view useful in the Aerospace industry-human factors context, as a means of taking into account many factors when we are considering how to most efficiently use man in a system. We offer it for consideration as a point of view which might serve in the instructional context as well, since it appears obvious that students are often task overloaded, as they are presented with massive amounts of information which they are expected to integrate and retain.

Section E. Overview of Implications for Instructional Technology

In this section, we will attempt to extract implications for the instructional technologies which appear to be common to part or all of the factors we have discussed. In so doing, we recognize that some of our generalized implications go beyond the data we have presented, and as such should be considered suggestive, rather than scientifically valid.

First, and perhaps foremost, we offer the suggestion that *the student acquiring a psychomotor skill, particularly a complex skill, will suffer as much or more from the effects of environmental stressors, toxic agents and drugs, time/work associated fatigue and task overload, as will personnel already trained in the task.* This is an important hypothesis, since the bulk of studies we have found use subjects already trained to some degree in their task. Some evidence for this view is provided in the data we have presented, the most dramatic example of which is the comparison of highly skilled pilot/astronauts versus relatively naive subjects engaged in a complex performance under conditions of environmental stress. For the former, no performance degradation was observed, whereas for the latter, significant degradation became apparent.

If this hypothesis is a fact, then we can generalize more directly to the learning context. The hypothesis probably holds for learning the more traditionally academic subjects as well, particularly for toxic agent and drug effects. With this orientation in mind, then, the following generalizations are offered:

1. When students are being trained in a complex psychomotor skill that they are later to apply in an operational or real-world setting, their subsequent performance will be affected by the four factors we have discussed in large part to the extent that they have substantially mastered, or "over-learned," the task complex. The degree of mastery will be reflected either by an absence, or by a delay over time in onset, of performance degradation.
   An important corollary of this generalization has direct implications for the instructional process. When the skill is being acquired via a student-instructor interactive relationship under conditions where environmental fatigue or other degrading factors are present (such as in flight or automobile driver training), the instructor may be relatively unaffected in terms of his performance, while the trainee is substantially affected. If the instructor is unaware of the differences in the effects on him, as compared to the effects on the student, he may attribute poor student performance to the wrong factors.
2. Complex psychomotor performance with highly cognitive elements (i.e., with substantial information integration requirements), will be more affected by all of the factors we have

discussed, except vibration and cold, than will the skills requiring more straightfoward stimulus-response reactions, or gross motor maneuvers. Vibration, on the other hand, impacts most seriously on the gross motor responses, as well as expediting onset of fatigue effects. Cold affects the performance of the extremities, seriously at temperatures at or below the mid-40's (F), though it appears not to affect the cognitive tasks during relatively short exposures. Fine motor coordination of the fingers, for example, deteriorates seriously at these low temperatures.

3. The physical condition of the subject can impact on performance very significantly in terms of the effects of all of the four factors, but is particularly evident in absence, or delay of onset, of effects of toxic agents and drugs, fatigue and environmental stressors.
4. When a complex psychomotor skill requires, in effect, simultaneous performance of a number of tasks, those less important secondary and tertiary tasks will be degraded by effects of environment, fatigue, toxic agents and drugs long before the perceived "primary" or most important tasks begin to deteriorate. This generalization has implications for the design of studies of effects of performance-degrading independent variables, as well as for performance and acquisition of psychomotor skills.
5. In acquiring psychomotor skills, an element of learning that is often overlooked, appears to be the fact that the subject learns to adapt to the effects of certain environmental toxic agent and drug stressors, such that his performance is subsequently less degraded by the stressor. This should not be considered a panacea, of course, but is worthy of note, particularly for vibration.
6. Evident throughout the domain of psychomotor performance research has been the apparent effect of that ill defined and difficult to manipulate factor we call motivation. Typically, motivation is discussed tautologically, with good performance generally being the basis for describing motivation as high, with the conclusion that high motivation contributes to good performance. The wealth of observations by researchers, instructors and students alike, however, of the impact of the "competitive spirit" or urgency to acquire perfection, on acquisition of psychomotor skills cannot be ignored. We simply wish to again emphasize that to the extent that the instructional technologies become adept at the art of motivation management, their students will probably progress at a far greater rate. We feel ourselves, unqualified to elaborate further on this difficult topic.

Because the task loading section identified a number of highly specific factors impacting on learning performance, these will be briefly summarized here. Viewing the psychomotor performance acquisition process from the task loading point of view we have selected the following factors as impacting significantly on skill acquisition:

1. In the instructor-student type of learning situation, the instructor should recognize that the intructional interchange itself is imposing an additional task on the student, with his inadequately developed skills. Thus, the instructor should be aware of when the student can attend to him and when he cannot. He should make his points briefly, with a good command of the language and clear articulation, or the student may turn him off "as an excess" to his task load.
2. Deficiencies in the man/equipment interfaces in a system a student is learning to operate will add to his task load and degrade his learning performance. These should at least be recognized in developing the training curriculum, and in the instructional process. When possible, both learning and performance considerations should impact on the design of these interfaces.
3. Frames-of-reference used for performance evaluation may differ substantially among instructors and evaluators, particularly for highly complex psychomotor tasks. To the extent that the divergences in these performance standards are not resolved, student confusion, wasted training time, and poor training will result.
4. Visual and auditory senses are generally a fundamental element of the performance, and of course the acquisition, of complex psychomotor skills. Clearer recognition of the characteristics of these sensor capabilities, and planning for their appropriate use, can, in effect, reduce the task load requirement placed on the performer. Existing information about these senses is sufficient to enhance performance if utilized. However, to fully take advantage of the sensory capabilities, substantially more information, particularly for the visual sense, must be acquired through research programmed to this end.

A two-fold factor of particular significance was brought out in our discussion of toxic and drug effects.

First, it is clear that the drugs in common use by the majority of contemporary Americans, including tobacco, alcohol, antihistimines, tranquilizers, motion sickness preventatives, etc., to say nothing of the illegal drugs, may impact significantly on psychomotor performance. The effects of combinations of these drugs and toxic agents on performance have, in some instances, already been shown to be synergistic. Harking back to our opening generalization in this section, if these drugs impact on performance, they certainly impact on acquisition of skills: and their effects are probably greater in the learning context. This factor should not go unrecognized in the instructional technologies, in terms of its implications for both students and instructors.

The second factor is the impact of our increasingly polluted atmospheric environment on performance. Of particular significance is the effect, on the one hand, and the prevalence, on the other hand, of CO in our atmosphere.

We are suggesting that the instructional technologies might be motivated to mount the band wagon for more sound research directed to defining more clearly the effects of these atmospheric pollutants on human performance, with the objective of assuring that valid standards for atmospheric quality are provided which in turn will safeguard both the health and capabilities of our people.

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